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Vol. CXLV.

EDITOR

K. HEADLAM-MORLEY

SECRETARY

ASSISTANT EDITOR

A. E. CHATTIN, B.Sc. (Hons. Met.), A.I.C.



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PREFACE.

THE present volume contains ten papers presented at the Annual General Meeting of the Institute held in London on May 7th, 1942; of these, five were presented under the auspices of the Joint Research Committees of the Institute and the British Iron and Steel Federation. The discussion and correspondence on these papers are also included, together with the authors' replies. In addition, a discussion on Open-Hearth Furnace Refractories is printed in this book, together with a publication notice of the "Second Report on Refractory Materials" (Special Report No. 28).

Section I. of this volume contains the above-mentioned material and also the Minutes of the Proceedings of the Meeting, including the Report of Council and Statement of Accounts for 1941, and the

Presidential Address.

Section II. is devoted to a survey of the literature on the manufacture and properties of iron and steel, and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the Bulletin of The Iron and Steel Institute, which is issued monthly.

In front of the title-page are inserted lists of Bibliographies and Special Reports issued by the Institute, together with a list of

Translations made available from the beginning of the year.

4, Grosvenor Gardens, London, S.W. 1. August, 1942.

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ABBREVIATIONS USED IN TEXT.

Å. Ångström unit(s). kg. kilogramme(s).	
A.C. air-cooled; alternating curkg.cal. kilogramme-cal rentcalories.	lory;
A.H. air-hardened. kg.m. kilogramme-me	etre(s).
amp. ampère(s). km. kilometre(s).	(-)-
amp.hr. ampère-hour(s). kVA. kilovolt-ampère	e(s).
atm. atmosphere(s) (pressure). kW. kilowatt(s).	
Bé. Baumé (scale). kWh. kilowatt-hour(s	3).
b.h.p. brake horse-power. lb. pound(s).	-
B.o.T. Board of Trade. L.F. low-frequency.	
B.Th.U. British thermal unit(s). m. metre(s).	
C. centigrade (scale). m.amp. milliampère(s).	
cal. calory; calories. mV. millivolt(s).	
c.c. cubic centimetre(s). max. maximum.	
c.d. current density. mg. milligramme(s)	
c.g.s. centimetre-gramme-second min. minimum; min	ute(s).
unit(s). ml. millilitre(s).	
cm. centimetre(s). mm. millimetre(s).	
coeff. coefficient. m.m.f. magnetomotive	force.
const. constant(s). N. normal (solution	
c.p. candle-power. N.T.P. normal tempe	rature and
cu. cubic. pressure.	
cwt. hundredweight(s). O.H. open-hearth; of	il-hardened.
D.C. direct current. O.Q. oil-quenched.	
dia. diameter(s). oz. ounce(s).	
dm. decimetre(s). p.d. potential difference	ence.
e.m.f. electromotive force. pH hydrogen-ion	concentra-
F. Fahrenheit (scale). tion.	
ft. foot; feet. r.p.m. revolutions per	minute.
it.lb. foot-pound(s). sec. second(s).	
g. gramme(s). sp. gr. specific gravity	•
gal. gallon(s). sq. square.	
H.F. high-frequency. T. tempered.	
h.p. horse-power. temp. temperature.	
h.p.hr. horse-power-hour(s). V. volt(s).	
hr. hour(s). VA. volt-ampère(s).	
in. inch; inches. Wh. watt-hour(s).	
in.lb. inch-pound(s). W.Q. water-quenched	i.
K. absolute temperature (Kel- yd. yard(s).	
vin scale). ° degree(s).	

SECTION I.

MINUTES OF PROCEEDINGS AND PAPERS OF THE IRON AND STEEL INSTITUTE.

ANNUAL MEETING 1942

MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

ANNUAL MEETING, 1942.

THE SEVENTY-THIRD ANNUAL MEETING OF THE IRON AND STEEL INSTITUTE was held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Thursday, May 7, 1942, at 2.45 p.m. Mr. John Craig, C.B.E., D.L., President, was in the Chair at the beginning of the proceedings, his place being taken later by Mr. James Henderson, President-Elect.

The Minutes of the previous Meeting were taken as read and confirmed.

Welcome to Visitors from Overseas.

The President (Mr. John Craig): My first duty is a pleasant one; it is to offer a very cordial welcome to our guests and visitors from other countries. We offer a special welcome to Dr. G. B. Waterhouse, who comes to us from Washington. (Applause.) We welcome him from Washington, but he got there via Sheffield. We also welcome some of our friends from Poland, who have been with us before. We are glad to see them again, and we trust that their time with us will be of interest to them. (Applause.) We also have a visitor from China, Dr. H. Lee, to whom we offer a cordial welcome. (Applause.) With Members present from Great Britain, the United States of America, Poland and China, we are certainly a representative gathering.

OBITUARY.

The President (Mr. John Craig): My next duty is a sad one; it is to refer to the loss that we have sustained by the death of some of our eminent Members; their names are given in the Report of Council before you. In addition, I desire especially to refer to the death of Sir William Bragg. He attended one of our Meetings two years ago, and rendered us the great service of delivering a most interesting and helpful address. His relationship with the

Institute was very cordial, and at all times he was willing to help

us in our work. His passing is a great loss to us.

It would be in accordance with the views of many of our Members, and particularly the younger ones, that I should also refer to the death of Mr. Percival Smith, who took a very prominent part in the work of the Institute and served it ungrudgingly, and with great loyalty and enthusiasm. His death at too early an age is a great loss to the industry.

In memory of these and of others whom I have not named, I

ask you to stand for a moment in silence.

The Members stood in silence for a few moments.

Award of the Bessemer Gold Medal for 1942 to Mr. E. G. Grace.

The President (Mr. John Craig): You may have seen the announcement already in the Press, but I have pleasure in stating that the Council unanimously decided to award the Bessemer Gold Medal for 1942 to Mr. Eugene Gifford Grace, Eng.D., President of the Bethlehem Steel Corporation, U.S.A. (Applause.) I feel sure that the decision of the Council will meet with the unanimous approval of all the Members, for we all recognise the great services which Mr. Grace has rendered to the industry not only in America but in its world-wide aspect, and his very friendly co-operation with the industry in this country. We have therefore asked him to accept the Medal. The diploma will be handed to him on our behalf by Mr. J. F. L. Elliot, a Member of Council, at present in the United States on official business, at a meeting of the American Iron and Steel Institute in New York. We hope that Mr. Grace will be able to come here after the war to receive the Medal in person. (Applause.)

HONORARY MEMBERS.

The President (Mr. John Craig): As was announced at the last Autumn Meeting, we invited Mr. Walter S. Tower, President of the American Iron and Steel Institute, to accept Honorary Membership of this Institute. He has done so with great cordiality, and has expressed himself as feeling highly honoured by the invitation. (Applause.)

The Council have unanimously decided to invite Mr. Harry Brearley, of Sheffield, a Bessemer Gold Medallist, to become an Honorary Member of the Institute in recognition of his distinguished services to the Institute and the industry. (Applause.) I am sure that that decision will give you all pleasure; we recognise his great ability, and many of us have read his delightful books.

PRESENTATION OF THE REPORT OF COUNCIL AND STATEMENT OF ACCOUNTS FOR 1941.

The Secretary (Mr. K. Headlam-Morley), at the invitation of the President, gave a brief summary of the Annual Report for 1941 (see pp.13 P-32 P). When dealing with Joint Meetings with Local Societies, he mentioned that the Council had instructed him to express the hope that it would be possible for more meetings of this character to be held in the future.

Mr. James Henderson (Hon. Treasurer; President-Elect) presented the Accounts for 1941 as set out in the Report of Council (see pp. 34 P-42 P). He said: Dealing first with the General Fund, the year's operations resulted in an excess of expenditure over income of roughly £752, after transferring £279 to Reserve Account, and writing off bad debts, mainly due to the outbreak of war with Japan, to the extent of £489. To what extent we may be able to recover that sum, or any part of it, from the Enemy Debts Commission remains to be seen, but we have thought it wise in the meantime to write it off.

With regard to the Trust Funds, the income of the Andrew Carnegie Research Fund exceeded the expenditure by £942. It may not be out of place for me to call the attention of Members to the fact that we are not receiving a reasonable number of applications for scholarships in connection with this Fund. It may be that it is not sufficiently widely known that this Fund exists for the purpose of assisting research, and that grants, usually of the order of £100 in a year, are given for suitable original research. We hope that Members will make this more widely known, so that

the purpose of this Fund shall be fully carried out.

The value of our investments has been well maintained; the market value at the end of the year exceeded their cost by £11,576. In the case of the House Fund and Industrial Subscriptions, the income from special subscriptions was £646 less than in the previous year. That is partly due to the operation of the Finance Act, which prevented our claiming a refund, on certain subscriptions, of more than 5s. 6d. in the £. We should like once again to thank the Companies, both large and small, which have subscribed so liberally both to the House Fund and to the Industrial Subscriptions Fund, because without these subscriptions it would be impossible for the Institute to carry on the full activities which it is carrying on to-day.

While the deficit to which I have referred has arisen on the year's operations, it is rather exceptional; on the whole, over a number of years, we have had a slight surplus of income over expenditure. It is not the purpose of the Institute, of course, to build up a big reserve, but rather to see that as much money as we can get for the purposes which we have in mind is wisely spent.

I can give you assurance that the most careful scrutiny has been made of current expenses, so that everything possible may be done

to secure the best use of the money at our disposal.

This is the last occasion on which I shall have the privilege of addressing you as Honorary Treasurer; as from this Meeting, that office passes to Mr. Richard Lyttelton, who will bring a new mind and fresh blood to the question of finance. Before laying down this office, I want to thank Mr. Headlam-Morley, our very capable Secretary, for his help in the work of supervising the finances of the Institute. He has made the task exceedingly pleasant and easy to carry out. I should also like to thank Miss Dowd, than whom no one could be more careful and consistent in handling the accounts.

With these remarks, I beg to present the Financial Statement.

The PRESIDENT: The Report of Council and Statement of Accounts have been submitted. Is it your pleasure that they be adopted?

The motion was carried unanimously.

The President: I should like to acknowledge, on behalf of the Council, the great services which have been rendered by Mr. Henderson since he accepted the position of Honorary Treasurer in 1934. He has given us very careful assistance in all financial matters, and part of the success of the Institute from a financial point of view is certainly due to his care in administration. I should like to see recorded in the annals of the Institute an expression of our very cordial thanks to Mr. Henderson for his excellent services during these eight years. (Applause.) I should also like to welcome Mr. Richard Lyttelton to this high office. I know from experience that he will very carefully look after all the money that you entrust to his care.

BALLOT FOR THE ELECTION OF NEW MEMBERS AND ASSOCIATES.

Professor F. C. Thompson (Manchester) and Mr. G. H. Godfrey Skellington (London), who had been appointed scrutineers of the ballot, reported that the following forty-eight candidates for membership and twenty-seven for associateship had been duly elected:

MEMBERS.

BADSEY, ROBERT Scunthorpe, Lines. BERRY, RICHARD WILLIAM, A.R.C.S., B.Sc. (Lond.) Sheffield. BIERNACKI, TADEUSZ London.

RETINITION PORTURE I ATTRICTOR D. IE.	TT 214 3-T 27 - 1 - 1
Brunton, Robert Laurence, B.Eng.	Hamilton, New Zealand.
CARTLEDGE, ALBERT EDWARD	Rotherham.
CIRCÉ, ARMAND, B.Sc. (Montreal),	THE A ROUTE
D.I.C. (Lond.)	Montreal, Canada.
CLARK, FRANCIS JAMES, B.Sc. (Hons.)	Barrow-in-Furness.
ELLIS, GEOFFREY WILLIAM	Norton, Sheffield.
FARLEY, GEORGE HENRY MORRIS,	
B.Sc. FISHER, ARCHIBALD	Greenford, Middlesex.
FISHER, ARCHIBALD	Motherwell, Lanarkshire.
GAWIN, BOLESLAW	London.
GLASS, WILLIAM	Charlton, London.
GLEN, JOHN, B.Sc., A.R.T.C.	Glasgow.
GREEN, AUSTIN JOHN, B.Sc.,	
A.R.C.S	Corby.
GRIFFIN, NOEL WILFRED, A.R.S.M.,	
B.Sc. (Eng. Met., Lond.)	Tinsley, Sheffield.
HAND, CLIFFORD, Assoc. Met.	Nether Edge, Sheffield.
HINSLEY, JOHN FREDERICK	Warley, Birmingham.
HULLOCK, JOHN DOMINIC	Coventry.
JACKSON, Miss LUCILLE, B.A., M.S.	Bridgeville, Pa., U.S.A.
KNOWLES, DENNIS, Assoc. Met. (Shef-	, ,
field)	Rotherham.
LAND, THOMAS, M.A. (Cantab.) .	Dore, Sheffield.
LLOYD, ANDREW BOLTON, B.A.	
(Mech. Sc., Cantab.)	Wednesbury, Staffs.
(Mech. Sc., Cantab.)	East Dene, Rotherham.
McMillan, Quintin Campbell,	Liano Lorio, Localitation
A.R.T.C	Motherwell, Lanarkshire.
A.R.T.C. Malmberg, R. E. Montgomery, James	Washington, Pa., U.S.A.
MONTGOMERY, JAMES	Motherwell, Lanarkshire.
MURRAY, WILFRED, A.I.C., F.C.S.	Liverpool.
Olszak, Feliks	London.
ORR, SYDENHAM DAVID	Mumbles, Swansea.
OSGOOD, GEOFFREY, M.A. (Cantab.),	
FIC	Stalybridge, Cheshire.
PADGETT, HARVEY, Assoc. Met. (Shef-	, , , , , , , , , , , , , , , , , , , ,
field)	Sutton-in-Ashfield, Notts.
PINCOTT, PERCY DOUGLAS	Bexley, Kent.
POCOCK, PERCY LOUIS	Oxhey, Herts.
RHODES, JOHN, B.Sc. (Lond.) .	Sheffield.
RIVETT. FRANCIS ANTONY, M.A.	_
RIVETT, FRANCIS ANTONY, M.A. (Hons., Cantab.)	Birmingham.
Donama Priving Louis	Rotherham.
ROBINSON, JAMES LEWIS, B.Sc.	
(Tech.), Ph.D.	Newark, Notts.
SADLER, ARTHUR VERNON	Leicester.
Scopes, Frederick	Nottingham.
SMITH, ERNEST	Jarrow-on-Tyne.
SMITH, ERNEST	Wharncliffe Side, Sheffield.
TWICGER THOMAS RAIDH	Coventry.
TWIGGER, THOMAS RALPH	Jamshedpur, India.
WHITE, HARRY ROWLAND,	o diametrial party and and
	London.
WILLIAMS, WILFRED STANLEY	Tirdeunaw, Swansea.
WILSON, PERCY HUTCHINSON	Nottingham.
William, I Bliot Hotellinon	

ASSOCIATES.

Langside, Glasgow. AITKEN, ANDREW IRVING, B.Sc. Bristol. ARCH, ROYSTON ERNEST CAMPBELL, GEORGE, B.Sc., A.R.T.C., Dalry, Ayrshire. A.I.C. COAKER, WILLIAM EDWARD FRED-Birmingham. ERICK Clydach, Swansea. COLE, JOHN PHILIP Clydach, Swansea. EVANS, BRINLEY . Prestwich. GODDARD, GEORGE HARDMAN, BERNARD MAWSON Barking, Essex. HARRIS, WILLIAM GODFREY . HARRY, EVAN DONALD . . Aylesbury, Bucks. Pontyberem, Llanelly. Redhill, Surrey. HENDERSON, SIDNEY GEORGE Johnson, Edward South Farnborough, Hants. Scunthorpe, Lines. Johnson, Ronald LLOYD, HENRY KENNETH MATHIAS Bridgend, Glam. Pittsburgh, Pa., U.S.A. Low, John R., Jun. MARRISON, PETER WALLER Ecclesall. Sheffield. Moss, Ashley Robert . Hampstead, London. NEWBY, JOHN Springs, Transvaal, S.A. Consett, Co. Durham. Preston, Clifford REDWOOD, KENNETH New Barking, Essex. ROCHFORD, FRANCIS N., B.Eng. Hayes, Middlesex. SINCLAIR, HAROLD BRADFORD Liverpool. Kearny, N.J., U.S.A. SMITH, GEORGE U., B.Sc., D.Sc. SORBY, WALTER . Sheffield. THOMPSON, KENNETH ELLIOTT Newport, Mon. WATKINS, BRYCHAN Ystradgynlais, Swansea, WILKINS, CHARLES ALFRED EDWARD Mossend, Lanarkshire.

ELECTION OF VICE-PRESIDENTS AND MEMBERS OF COUNCIL.

The Secretary (Mr. K. Headlam-Morley): In accordance with Bye-Law 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting in 1941 as being due to retire at the present Annual Meeting:

Vice-Presidents: Dr. C. H. Desch, F.R.S., Dr. W. H. Hatfield, F.R.S., and Sir William Larke, K.B.E.

Members of Council: Mr. W. J. Brooke, Mr. E. J. Fox, Mr. J. Sinclair Kerr, Dr. T. Swinden and Mr. A. B. Winder.

No other Members having been nominated up to one month previous to the present Annual Meeting, the retiring Vice-Presidents and Members of Council are now presented for re-election. (Agreed.)

WILLIAMS PRIZE AND ANDREW CARNEGIE MEDAL.

The Secretary (Mr. K. Headlam-Morley): No award of the Williams Prize or of the Carnegie Gold Medal has been made for the year 1941.

Andrew Carnegie Research Scholarship.

The Secretary (Mr. K. Headlam-Morley): I have to announce that a further grant to the following candidate was made by the Council in 1941:

M. Balicki (University College, Swansea)-£100, subsequently increased to £200 (second grant), in aid of the continuation of a research on the softening and recrystallisation phenomena of cold-worked mild

"RAZOR BLADES FOR BRITAIN" MOVEMENT.

The Secretary (Mr. K. Headlam-Morley): The "Razor Blades for Britain" Movement has presented a large number of razor blades, collected by American steel operatives, to The Iron and Steel Institute for distribution to British steel operatives. The blades were handed over by Lady Beatty, as Vice-Chairman of the "Bundles for Britain" Movement in this country, to Mr. Henderson, representing the Institute, and to Sir William Larke, representing the British Iron and Steel Federation, and they will be distributed to individual steelmakers at plants throughout the country. Attached to each bundle of blades is a label giving the name and address of the donor; it is the hope of the "Razor Blades for Britain" Movement that the recipients in this country will write personally to thank those who have sent them from the other side of the Atlantic.

The President (Mr. John Craig): We all appreciate this gesture by our friends in America; it is another sign of the intense desire of the men in our industry on the other side of the Atlantic to join forces with us, and we value this particular gift all the more, since the razor blades were collected before our two countries became formal allies. These blades should certainly help to improve the appearance of British steelmakers. (Applause.)

INDUCTION OF THE PRESIDENT-ELECT, Mr. JAMES HENDERSON.

The RETIRING PRESIDENT (Mr. John Craig): I now come to the final duty which I am called upon to discharge, and which I discharge with great pleasure and with some regret. I confess that during my occupancy of the Presidential Chair I have enjoyed the work. I have appreciated the Meetings, I have learned a good deal, and I have enjoyed what may be called the social elements of our Institute, although we have not had the opportunity of developing that phase of our activities as we would have wished to do.

I now have very great pleasure in asking Mr. James Henderson, the President-Elect, to take the Chair. He comes to this high office—the highest office on the technical side of the industry which we can offer to anyone—fully qualified by experience, by knowledge and by loyalty to the Institute to occupy this position. We trust that he will be the President who will welcome peace to this country and to our industry. We look forward with great hope to his period of office, and we wish him well. (Applause.)

Mr. John Craic then left the Chair, which was taken, amid applause, by the incoming President, Mr. James Henderson.

The Incoming President (Mr. James Henderson): I should like to say, very briefly, how much I appreciate the honour that you have done me to-day. It is impossible for me adequately to express my gratitude to you, but I hope that, when the time comes for me to lay down this office, I shall be able to feel that my time in your service has not been entirely mis-spent. This is one of the few occasions on which I regret that I cannot put the clock back and be five or ten years younger. If I follow in the footsteps of my predecessor, Mr. John Craig, I shall not go far wrong.

VOTE OF THANKS TO THE RETIRING PRESIDENT.

The President (Mr. James Henderson): Mr. John Craig said that he concluded his term of office with some regret, and it falls to me to express our regret that his term of office should have come to an end. I hope that he will continue to enjoy health and prosperity in his other activities, and I know that his slate is very full of other work. We should, I know, like to put it on record in the annals of the Institute that we appreciate what he has done during his term of office. It has been done in most difficult circumstances. He has travelled up one night by train and back the next, and how he manages to look so well on it I do not know! That he has done so much for the Institute in these difficult circumstances is something for which we must be very grateful, and on your behalf I tender to him our most hearty thanks for his conduct as our President. (Applause.)

PRESENTATION OF THE PRESIDENTIAL ADDRESS.

The President (Mr. James Henderson) then delivered his Presidential Address (see pp. 43 P-50 P).

Sir William Larke, K.B.E. (Vice-President, London): It is my privilege and pleasure to express on your behalf and on my own our cordial thanks to our President for his stimulating Address. If it was not for the Censor, what a tale he could unfold! As it is, however, I think that he has given us an Address which is a model of what a Presidential Address should be. In so far as it was a record of the past, it was so given as to indicate the means whereby we could build the future on that experience, and in so far as he looked to the future he stimulated our thought, particularly in his review of our own research progress and activities.

Personally, I 'hold the view rather strongly that industrial research should be directed in the first instance to the general improvement of industrial efficiency and to the discovery of new products and so forth; but in so doing we must remember that industry controls finance and is able, therefore, to provide in the appropriate quarters the requisite finance to ensure that such fundamental research is carried out as will safeguard us in the future. We have these discussions in our Research Council quite frequently, and there are natural divergencies of view; but broadly speaking we arrive—and I think that our programme shows it—at an effective compromise policy, and I feel that no research organisation in the country has proved more effective than our own in conveying and translating the results of that research into the

practice of the industry.

Mr. Henderson referred to Mr. Mannaberg, and I know he would like me to mention one incident as a tribute to Mr. Mannaberg's work as a pioneer. On one occasion Mr. Mannaberg told me about his being sent to Frodingham. As sometimes happens even to-day, the estimates for the building of that steelworks had been vastly exceeded, and this young man, then in his middle twenties, was faced with the possibility of the work being half to three-quarters finished and there being no funds with which to complete it. The banks refused to advance the money to the then proprietors. Mr. Mannaberg said "I am not a wealthy man; I have only my salary of £300 or £400 a year, but I am ready to back this by taking half my salary in shares." The banks said "Well, if this young man has so much confidence, we will advance the money," and they advanced the money on that young man's conviction and faith in himself, rather than on the credit of wealthy That is an example to young men who find themselves in the position of being pioneers in any movement; they must be prepared to stake their own livelihood on the faith that they have in themselves.

Mr. Henderson is a modest man and dislikes praise. I want only to say this, that Mr. Henderson, all through the period during which he has been connected with them, has been a very strong supporter of our research activities. He has given us active, personal work and invaluable support whenever we needed help with the industry. Personally, I am very grateful to him for that, and I am sure that you are as grateful as I am to him for having given us such a stimulating Address, which gives us not only thought for the future but a basis for future action.

Dr. W. H. Hatfield, F.R.S. (Vice-President, Sheffield): I should like to second this vote of thanks to Mr. Henderson for his valuable Address. I was delighted to see him take the Chair, sorry as I was to see Mr. Craig vacate it. In listening to the Address, I felt that Mr. Henderson had been rather modest about the part that he had played. We know that Mr. Mannaberg was a great pioneer, but pioneers can do little unless they are ably supported by a brilliant group; and I know that Mr. Henderson spent long years of heavy work in seeing Mr. Mannaberg through his many difficulties before himself taking over responsibility for the works, which he then greatly developed.

No one is better qualified to talk about the subject of research than Mr. Henderson, who, before taking the Presidency of The Iron and Steel Institute, had been President of the Federation—a good apprenticeship, if I may say so! He has also been President of the Lincolnshire Iron and Steel Institute, and he was for some considerable time Chairman of the Iron and Steel Industrial Research Council; and I can vouch for the fact that we were always fully supported by Mr. Henderson as regards any facilities or

money that we required to carry out our ideas.

Mr. Henderson has given us a valuable sketch of our research system, but I think he might have added that as it stands it might be characterised as an indigenous growth, a truly British growth. I do not think that what is, after all, such a loose organisation could have developed and been so effective in any other country. Each country must provide its own methods and means, and I for one think that our system has been very good. On the other hand, I agree with Mr. Henderson that with the passing of time we may devise even better means of co-ordinating more closely our various activities. I have much pleasure in seconding the vote of thanks, and I hope that Mr. Henderson will have a very happy period of office.

The vote of thanks was carried unanimously, with acclamation.

Complete List of Papers and Report Presented at the Annual General Meeting, 1942.

- J. H. Andrew and H. Lee: "The Work-Hardening and Ageing of Steel."
- J. H. Andrew and H. T. Protheroe: "Investigation of the Influence of Mould Friction on Tearing in Castings." (Paper No. 2/1941 of the Steel Castings Research Committee).
- W. Hume-Rothery, F.R.S., G. V. Raynor and A. T. Little: "The Lattice Spacings and Crystal Structure of Cementite."
- W. Hume-Rothery, F.R.S., G. V. RAYNOR and A. T. Little: "On Carbide and Nitride Particles in Titanium Steels."
- C. H. M. Jenkins, G. A. Mellor and E. A. Jenkinson: "The Investigation of the Behaviour of Metals under Deformation at High Temperatures.—Part II."
- D. A. OLIVER and T. LAND: "The Temperature Distribution in the Liquid Steel in Various Steelmaking Furnaces." (Paper No. 10/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee)).
- N. J. Petch: "The Positions of the Carbon Atoms in Austenite."
- "First Report of the Standard Methods of Analysis Sub-Committee." (Paper No. 11/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Standard Methods of Analysis Sub-Committee)).
- "Protective Painting of Structural Steel." By the Protective Coatings Sub-Committee. (Paper No. 5/1941 of the Corrosion Committee (submitted by the Protective Coatings Sub-Committee)).
- "Second Report on Refractory Materials." A Report by the Joint Refractories Research Committee of the Iron and Steel Industrial Research Council and the British Refractories Research Association. (The Iron and Steel Institute, 1942, Special Report No. 28).
- "Third Report of the Liquid Steel Temperature Sub-Committee." (Paper No. 9/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee)).

Presentation of Papers.

A list of all the papers included in the programme of the Meeting will be found on the preceding page; the following were presented for verbal discussion:

"Third Report of the Liquid Steel Temperature Sub-Committee." (Paper No. 9/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee)).

"The Temperature Distribution in the Liquid Steel in various Steelmaking Furnaces," by D. A. OLIVER and T. LAND. (Paper No. 10/1942) of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee)).
"The Work-Hardening and Ageing of Steel," by J. H. Andrew and

H. LEE.

The first two papers were discussed jointly.

The following paper was also presented, but time did not permit of its discussion:

"First Report of the Standard Methods of Analysis Sub-Committee." (Paper No. 11/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Standard Methods of Analysis Sub-Committee)).

On the motion of the President, a vote of thanks was accorded to the authors for their papers.

The proceedings then terminated.

REPORT OF COUNCIL FOR 1941.

THE Council submit this, their Annual Report and Statement of Accounts for the year 1941 to Members for their approval at the Seventy-Third Annual General Meeting of The Iron and Steel Institute. Information up to 31st March, 1942, has been included

in some sections of the Report.

The work of the Institute, adjusted to meet war-time conditions, has been actively continued. The Joint Research Committees have been engaged on enlarged programmes of research which are mostly of consequence to the prosecution of the war; special Meetings have been arranged in order to make information available to sections of the industry; increasing use has been made of the Library and Information Departments and the number of volumes loaned during the year constitutes a record. The Annual and Autumn Meetings were held and the Journal and Monthly Bulletin of Abstracts published as usual.

ROLL OF THE INSTITUTE.

The Membership of the Institute at 31st December, 1941, was two thousand five hundred and fifty-six, a decrease of a hundred and ten from the figures of the previous year. This is due to the loss of Members resident in countries now involved in the war, and Members resident on the Continent whose subscriptions for the year were unpaid have been omitted. The home membership is greater than on any previous occasion. Details of the membership compared with those of the three preceding years are as follows:

		31/12/'38.	31/12/'39.	31/12/'40.	31/12/'41.
Patron		1.	1	1	~ 1
Honorary Members	۰	13	15	14	. 15
Life Members .	۰	69	68	67	60
Ordinary Members:					
Home		1560	1622	1673	1696
Overseas		781	785	663	513
Associates		206	213	248	271
		2630	2704	2666	2556
			==		

The above total membership figures for each year include seven Members for 1938 and eight for the other years whose names were retained in the List of Members in an honorary capacity by order of the Council.

Variations in the membership since the formation of the

Institute in 1869 are shown in Fig. 1.

During the year twenty-six Members and one Associate resigned and the deaths of twenty-eight Members were reported.

Six Life Members and thirty-five ordinary Members of Japanese, Hungarian and Rumanian nationality have ceased to be Members of the Institute in accordance with Bye-Law No. 36, as well as two Members of Finnish nationality who had been placed on a Suspense List as from 1st January, 1940. (Since the outbreak of war on 3rd September, 1939, the membership of one hundred and twenty-two Members has terminated under this Bye-Law.)

The membership as stated does not include twenty-two Members and eight Associates whose names have been placed on a Suspense List at their request owing to absence on military duties, nor the names of one hundred and twenty-seven Members and one Associate resident abroad whose subscriptions had not been paid before the end of the year and who have also been placed on a Suspense List as from 1st January, 1941. These include one hundred and seven Members resident in Belgium, China, Denmark, France, Holland, Luxemburg and Norway, and twenty Members and one Associate resident in Spain, Sweden and Switzerland. The total placed on this list since the outbreak of war is two hundred and twenty-four Members and one Associate.

A further reduction, not exceeding forty-four Members and one Associate, in the numbers of Members and Associates resident on the Continent and in China and Hongkong must be anticipated, and it is proposed that those whose subscriptions remain unpaid at the end of the current year shall also be placed on the Suspense List

as from 1st January, 1942.

During the year under review one hundred and eighteen new Members and seventy new Associates were elected. These include forty-four Members and twenty Associates nominated by Companies which subscribe to the Special Subscriptions Fund, and twenty-nine Members and thirty-eight Associates who joined under the scheme of collaboration with the Institute of Metals. Twenty-six Associates were transferred to Membership and fifteen former Members were reinstated.

OBITUARY.

The Council regret to record the deaths of the following twentysix Members which occurred during the year 1941:

ALLAN, JAMES BOYD (Prestwick, Ayr-	
shire)	2nd January.
ALLAN, JOHN BOTCHERBY (Chesterfield).	13th February.
BIRKETT, M. S. (London)	6th August.
Butler, Harold (Halifax)	December.
CARTER, H. E. (London)	21st June.
Clasen, Bernard (London)	12th July.
COLDWELL-HORSFALL, H. H. (Birming-	<i>U</i>
ham)	2nd April.
	13th December

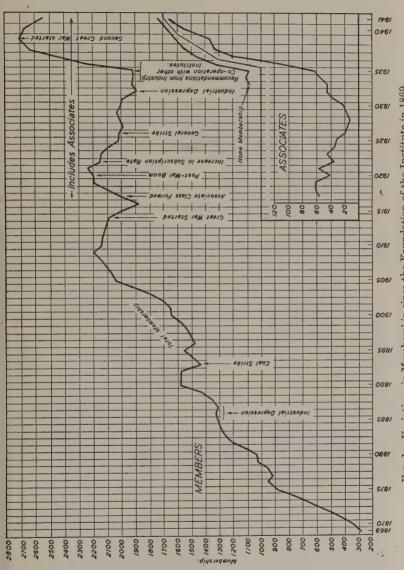


Fig. 1.—Variations in Membership since the Foundation of the Institute in 1869.

Deschamps, J. (Hitchin)		15th December.
Elliot, T. G. (Sheffield)		25th May.
FAIRGRIEVE, J. G. (Cambuslang, Lanar	rk-	
shire)		23rd July.
Firth, F. W. (Sheffield)		14th November.
FLEMING, B. A. (Scunthorpe, Lines.)		April.
GWYNN, R. H. B. (London)		21st April.
HEMMING, F. J. (Walsall, Staffs.) .		10th November.
HOPKINS, CLIFFORD (Swansea) .		May.
LARSON, E. H. (Värmlands Björnebor	rg,	
Sweden)		5th April.
Morgan, W. T. (Rochester, N.Y., U.S.A.		1st February.
Peech, A. O. (London) (Vice-President)) .	22nd March.
ROYSTON, HAROLD (Blackpool) .		
SANDBERG, C. P. (London)		26th June.
SANDBERG, N. E. F. (London) .		10th March.
TYZACK, J. S. (Sheffield)		15th November.
Walsh, C. J. (Retford, Notts.) (Memb	er	
of Council)	. •	22nd February.
WARD, JOSEPH (Sheffield)		7th July.
WILLIAMS, EDWARD (Yarm, Yorkshire)		2nd October.
The deaths of the following six Mehan 1941, but were not previously repor		
CLAVEY, G. A. (Liverpool)		July, 1940.

FINDLEY, A. I. (New York, U.S.A.) 12th December, 1940. Frost, S. (Sheffield) November, 1940. MAUDE, J. C. (Moseley, Birmingham) June, 1940. POLLARD, F. E. (London) April, 1940. STOBIE, VICTOR (Harrogate, Yorkshire). 31st December, 1940.

Mr. A. O. Peech was a Vice-President and Mr. C. J. Walsh a Member of Council, having previously also been an Honorary Member of Council during his term of Presidency of the Lincolnshire Iron and Steel Institute; reference to their deaths was made at the Annual General Meeting in May, 1941. Mr. C. P. Sandberg and Mr. H. H. Coldwell-Horsfall had been Members of the Institute for more than forty years, having been elected in 1898 and 1899, respectively. Obituary notices will be found in the No. II. volume of the *Journal* for 1941.

FINANCE.

(The Statement of Accounts for 1941 is attached to this Report.)

General Fund.—The year's operations resulted in an excess of expenditure over income of £752 after transferring £279 to Reserve Account and writing off bad debts, which were due mainly to the outbreak of war with Japan, to the extent of £489. The deficit has

been carried to the Balance Sheet and deducted from previously

accumulated surpluses.

Trust Funds.—The income of the Andrew Carnegie Research Fund exceeded expenditure by £942. This is due to the small expenditure on scholarships, for which there are now few applications. The resulting addition to previously accumulated surplus income will make greater expenditure on scholarships possible after the war.

The accounts of the Williams Prize Fund show a surplus of £23, one award at the normal rate of £100 having been paid during the year. The Hon. R. G. Lyttelton has succeeded the late Sir Harold Carpenter, F.R.S., as a trustee of the Andrew Carnegie Research

Fund and of the Williams Prize Fund.

Investments.—The value of investments of the General Fund and Trust Funds has been well maintained, and the market value at the end of the year exceeded their cost, at which they are taken into

the Balance Sheets, by a total of £11,576.

House Fund and Industrial Subscriptions.—Income from special subscriptions at £4387 was £646 less than in the previous year. This is largely the result of the provision of the Finance Acts, which limited the amount of income tax recoverable on subscriptions paid under covenant to 5s. 6d. New subscribers included The South African Iron and Steel Industrial Corporation, Ltd., and The Welsh Plate & Sheet Manufacturers' Association.

The Council again wish to express their appreciation of the generous response to their appeal for industrial subscriptions, without which the activities of the Institute could not be maintained. The following is a list of Companies and Associations from which contributions were received during the year: Edgar Allen & Co., Ltd.; Ashmore, Benson, Pease & Co., Ltd.; Babcock & Wilcox, Ltd.: Bairds & Scottish Steel, Ltd.; Baldwins, Ltd.; Arthur Balfour & Co., Ltd.; Frederick Braby & Co., Ltd.; Bradley & Foster, Ltd.; The Briton Ferry Steel Co., Ltd.; Burnell & Co., Ltd.; The Butterley Co., Ltd.; Bynea Steel Works, Ltd.; Colvilles, Ltd.; Consett Iron Co., Ltd.; The Darlington Forge, Ltd.; The Darwen & Mostyn Iron Co., Ltd.; Darwins, Ltd.; Dorman, Long & Co., Ltd.; English Steel Corporation, Ltd.; Thos. Firth & John Brown, Ltd.; General Refractories, Ltd.; Guest Keen Baldwins Iron & Steel Co., Ltd.; J. J. Habershon & Sons, Ltd.; Hadfields, Ltd.; N. Hingley & Sons, Ltd.; Kayser, Ellison & Co., Ltd.; The Lancashire Steel Corporation, Ltd.; Arthur Lee & Sons, Ltd.; The Llanelly Steel Co. (1907), Ltd.; John Lysaght, Ltd.; McCall & Co. (Sheffield), Ltd.; The Millom & Askam Hematite Iron Co., Ltd.; The Mond Nickel Co., Ltd.; Neepsend Steel & Tool Corporation, Ltd.; Newton Chambers & Co., Ltd.; The Oughtibridge Silica Firebrick Co., Ltd.; The Park Gate Iron & Steel Co., Ltd.; The Patent Shaft and Axletree Co., Ltd.; Raine & Co., Ltd.; Round Oak Works, Ltd.; Simon-Carves, Ltd.; Walter Somers, Ltd.; The South African Iron and Steel Industrial Corporation, Ltd.;

South Durham Steel & Iron Co., Ltd.; The Stanton Ironworks Co., Ltd.; The Steetley Lime & Basic Co., Ltd.; John G. Stein & Co., Ltd.; Stewarts & Lloyds, Ltd.; John Summers & Sons, Ltd.; Tata, Ltd.; Taylor Bros. & Co., Ltd.; Richard Thomas & Co., Ltd.; The Tinsley Rolling Mills Co., Ltd.; The Union Steel Corporation (of South Africa), Ltd.; The United Steel Companies, Ltd.; The Upper Forest & Worcester Steel & Tinplate Works, Ltd.; Vickers, Ltd.; The Wellman Smith Owen Engineering Corporation, Ltd.; The Welsh Plate & Sheet Manufacturers' Association; Whitehead Iron & Steel Co., Ltd.; The Woodall-Duckham Vertical Retort and Oven Construction Co. (1920), Ltd.

CHANGES ON THE COUNCIL.

The President announced at the Autumn Meeting that Mr. James Henderson had been unanimously nominated to succeed him at the Annual Meeting in 1942, and that the Hon. R. G. Lyttelton had accepted an invitation to become Honorary Treasurer in succession to Mr. James Henderson on his election to the Presidency.

During the year Dr. Andrew McCance was nominated a Vice-President; Professor John Harold Andrew, D.Sc. (Sheffield University), and Mr. Neville H. Rollason (Messrs. John Summers & Sons, Ltd.; The Shelton Iron and Steel Co., Ltd.) were elected

Members of Council.

The Presidents of the Sheffield Society of Engineers and Metallurgists (Mr. W. E. Bardgett) and of the Sheffield Metallurgical Association (Dr. W. H. Hatfield, F.R.S., Vice-President) accepted invitations to become Honorary Members of Council during their periods of office; Dr. E. Gregory succeeded Mr. Bardgett on 1st January, 1942.

In accordance with Bye-Law No. 10, the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting as being due to retire at the Annual General

Meeting in 1942:

Vice-Presidents: Dr. C. H. Desch, F.R.S., Dr. W. H. Hatfield, F.R.S., and Sir William J. Larke, K.B.E.

Members of Council: Mr. W. J. Brooke, Mr. E. J. Fox, Mr. J. Sinclair Kerr, Dr. T. Swinden and Mr. A. B. Winder.

No other Members having been nominated up to one month previous to this Annual Meeting, the retiring Members are presented for re-election.

BESSEMER GOLD MEDAL.

The Bessemer Gold Medal for 1941 was awarded to Dr. Thomas Swinden, D.Sc. (The United Steel Companies, Ltd.), in recognition of the value of his original investigations into the metallurgy of steel and of his eminent services to the organisation and direction of research in the steel industry.

The Council have decided to award the Bessemer Gold Medal for 1942 to Mr. Eugene Gifford Grace, Eng.D. (Bethlehem Steel Corporation), in recognition of his valuable services to the iron and steel industries and in appreciation of all that he has done to foster technical, scientific and industrial collaboration between the industries in Great Britain and the United States of America.

HONORARY MEMBER.

The President announced at the Autumn Meeting that the Council had invited Mr. Walter S. Tower, President of the American Iron and Steel Institute, to become an Honorary Member.

Andrew Carnegie Medal.

No award of the Andrew Carnegie Medal was made.

WILLIAMS PRIZE.

No award of the Williams Prize was made.

ABLETT PRIZE.

No papers were submitted in competition for the Ablett Prize of £50 offered by Captain C. A. Ablett, O.B.E., B.Sc., M.Inst.C.E. (Cooper Roller Bearings Co., Ltd.), for a paper on a subject connected with engineering in iron or steel works.

Andrew Carnegie Research Scholarships.

A further grant to the following candidate was made by the Council for 1942:

M. Balicki (University College, Swansea).—£100, subsequently increased to £200 (second grant), in aid of the continuation of a research on the softening and recrystallisation phenomena of cold-worked mild steels.

THE WORSHIPFUL COMPANY OF BLACKSMITHS.

In accordance with an understanding with the Wardens of the Worshipful Company of Blacksmiths, an application for admission to the Company was considered, and Mr. W. Robson Brown (Messrs. Richard Thomas & Co., Ltd.) was recommended by the Council for admission to the Company.

Honours Conferred on Members.

(To March 31st, 1942.)

The Council tender their warm congratulations to Members of the Institute on honours and appointments received during the period under review.

Sir Andrew Duncan, G.B.E., M.P., who became Minister of



Supply in 1940, was reappointed President of the Board of Trade, a position that he had held earlier in the war; early in the present year (1942) he again became Minister of Supply. Mr. C. U. Peat, M.P., became a Parliamentary Private Secretary to the President of the Board of Trade, and in March, 1942, Joint Parliamentary Secretary, Ministry of Supply. Dr. H. J. Gough, M.B.E., F.R.S., was appointed Deputy Controller General of Research and Development in the Ministry of Supply, and Dr. J. W. Jenkin became Advisor on Steel Tubes to that Ministry. Mr. A. Dunbar was made Director General of Materials Production and Deputy Controller General of the Production Committee, and Mr. W. C. Devereux, Controller of North American Aircraft Production (he resigned this position later in the year), both under the Ministry of Aircraft Production. Dr. R. J. Sarjant and Mr. J. G. Bennett accepted membership of the National Fuel Efficiency Committee of the Mines Department, and Mr. A. T. Green joined the Simmonds Committee which advises the Minister of Works on steps to be taken to increase efficiency and economy in the manufacture of bricks. Mr. R. A. MacGregor was appointed Director of Metals for India, and Major-General K. C. Appleyard, O.B.E., who, earlier, had been made an Additional Commander of the Military Division of the Order of the British Empire, became Director of Emergency Reconstruction, Ministry of Works and Buildings; he resigned from this post in March, 1942. Dr. A. McCance joined a new committee appointed by the Scottish Development Council to make investigations and formulate recommendations for a post-war economic plan for Scotland. Professor G. B. Waterhouse is now the technical consultant to the Steel Section of the Office of Production Management, Washington, U.S.A.

Since the New Year (1942) Sir William Larke, K.B.E., has become Controller of Non-Ferrous Mineral Development in the United Kingdom, and Sir Samuel Beale, K.B.E., has been appointed Chairman of the Business Members of the Industrial and Export

Council.

In 1941 Knighthoods were conferred on Mr. Alan J. Grant, Mr. F. E. Rebbeck and Mr. A. Matthews, O.B.E. Mr. R. Alsop and Captain H. Leighton Davies were appointed Commanders of the Order of the British Empire. In 1942 Mr. R. W. Allen, C.B.E., and Captain R. S. Hilton received Knighthoods, and Mr. S. R. Beale was made a Knight of the Order of the British Empire.

Sir Andrew Duncan, G.B.E., M.P., was elected an Honorary Member of the Institution of Electrical Engineers in appreciation of his outstanding public services, particularly to the electrical industry, during his eight years of office as the first Chairman of the Central Electricity Board. Dr. M. A. Grossmann received the Henry Marion Howe Medal of the American Society of Metals, Professor J. M. Lessells was a joint recipient of the Louis E. Levy Medal of the Franklin Institute, Mr. Essington Lewis received the

Australian Institute of Mining and Metallurgy Medal for 1940 in recognition of his invaluable work in the development of the iron, steel and allied industries in Australia, and Mr. H. J. Merchant was awarded the Staffordshire Iron and Steel Institute's Research Medal and Prize for his paper on "Steel for Sheets." Dr. Bradley Stoughton, who had been elected a Vice-President of the American Society for Metals in 1940, became President of that body in 1941. Mr. G. R. Bashforth was elected President of the Staffordshire Iron and Steel Institute for a third year, and Dr. W. H. Hatfield. F.R.S., and Professor J. H. Andrew were re-elected Presidents of the Sheffield Society of Engineers and Metallurgists and of the Institute of Vitreous Enamellers, respectively. Mr. W. E. Bardgett became President of the Sheffield Metallurgical Association, and was followed in January, 1942, by Dr. E. Gregory. Mr. W. W. Wood is Master Cutler of the Cutler's Company in Hallamshire for the third time—he had previously held this position in 1924 and 1940-41. Mr. Alfred Scholes was elected a Vice-President of the Cleveland Scientific and Technical Institution. Mr. W. P. Digby was made a Fellow of the Institute of Physics. Since the New Year, Mr. C. C. Paterson has been elected a Fellow of the Royal Society and Mr. David E. Roberts an Honorary Life Member of the Institution of Mechanical Engineers. Dr. R. Seligman has been appointed Chairman of the Condenser Tube Corrosion Research Sub-Committee of the British Non-Ferrous Metals Research Association.

Dr. S. F. Dorey was elected President of the British Association of Refrigeration and Mr. T. J. Kauffeld became a Vice-President of the American Type Founders. The Right Hon. the Earl of Dudley, M.C., became the first President of the Midland Association of Building Societies. Mr. P. W. Wood became a Magistrate for the Consett area, and Dr. J. E. Hurst a Justice of the Peace for the City of Lichfield, while Mr. Robert Malcolm became a member of

Stirling Town Council.

Professor C. O. Bannister retired from the Chair of Metallurgy at Liverpool University. He was the first holder of this appointment, and at his retirement he had completed twenty-one years in the Chair.

PRESENTATIONS TO THE INSTITUTE.

Sir Robert Hadfield, Bart., D.Sc., D.Met., F.R.S.—The Council gratefully acknowledge receipt of about a hundred and thirty books and pamphlets on mining and metallurgy, the majority consisting of valuable early printed works, which had belonged to the late Sir Robert Hadfield (Past-President and Bessemer Gold Medallist), and also a bronze plaque, showing Sir Robert's head and shoulders in bas-relief, presented by Messrs. Hadfields, Ltd., through the kind offices of Mr. P. B. Brown and Mr. J. B. Thomas.

Early Bessemer Plants.—The Council also gratefully acknow-

ledge receipt of a number of early designs of Bessemer plants and connected machinery presented by Mr. W. A. Woodward.

STAFF.

In addition to the members of the Staff reported a year ago as serving in the Armed Forces, Mr. R. F. Flint has now joined the Royal Air Force. Mr. H. Davison has been granted a Commission in the Pioneer Corps.

MEETINGS.

Annual Meeting.

The Annual Meeting was held at Grosvenor House, Park Lane, London, W.1, on Thursday, 1st May, 1941. The President, Mr. John Craig, C.B.E., D.L., was in the Chair. Eight papers, including three submitted under the auspices of Joint Research Committees of the Institute and the British Iron and Steel Federation, were presented, and four papers were discussed during the Meeting.

Members' Luncheon.

As in the previous year, the Annual Dinner was replaced by a Members' Luncheon; it took place at Grosvenor House, Park Lane, London, W.1, at 1 P.M., on 1st May, and preceded the Annual Meeting. Nearly five hundred and fifty Members and their friends, including ladies, were present; the following proposed or responded to toasts:

The Right Hon. R. G. Menzies, P.C., K.C., LL.D. (Prime Minister and Minister for Co-ordination of Defence, Australia).

Mr. John Craig, C.B.E., D.L. (President).

His Excellency M. Joseph Bech (Minister of Foreign Affairs of the Grand Duchy of Luxemburg).

The Bessemer Gold Medal for 1941 was presented to Dr. T. Swinden during the Luncheon.

Autumn Meeting.

The Autumn Meeting was held at the offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on the afternoon of Tuesday, 25th November, 1941, the President, Mr. John Craig, C.B.E., D.L., being in the Chair. Twelve papers were presented, including six submitted by Joint Research Committees of the Institute and the British Iron and Steel Federation, one report on a research carried out with the aid of a grant from the Andrew Carnegie Research Fund and one report by a Joint Panel working under the ægis of

the Iron and Steel Industrial Research Council and the Council of the British Refractories Research Association; of these, three were discussed.

RELATIONS WITH OTHER SOCIETIES AND TECHNICAL Institutions.

(For the period 1st April, 1941, to 31st March, 1942.)

So far as the circumstances of the war have permitted, friendly contacts have been maintained with Scientific Societies and Technical

Institutions in Great Britain and countries overseas.

Close collaboration with the Institute of Metals has been continued. The number of Members and Associates who are also Members or Student Members of that Institute has increased during the year by one hundred and seventy-nine to eight hundred and sixty-one, more than one-third of the total membership of the Institute.

The Council record with pleasure the continued friendly relations existing between this Institute and the following Societies on the same basis as in previous years:

Cleveland Institution of Engineers. Ebbw Vale Metallurgical Society. Lincolnshire Iron and Steel Institute. Manchester Metallurgical Society. Newport and District Metallurgical Society. Sheffield Metallurgical Association. Sheffield Society of Engineers and Metallurgists. Staffordshire Iron and Steel Institute. Swansea Technical College Metallurgical Society. West of Scotland Iron and Steel Institute.

Joint Meetings.

The following are particulars of Joint Meetings held with Local Societies:

Tuesday, 8th July, 1941: Swansea Technical College Metallurigcal Society.

> Place and Time: Beaufort Hall, Mackworth Hotel, High Street, Swansea, at 6.15 P.M.

> Chairman: Mr. O. J. Thomas, President of the Swansea Technical College Metallurgical Society.

Papers:

"The Influence of some Special Elements upon the Strain-Ageing and Yield-Point Characteristics of Low-Carbon

Steels," by C. A. Edwards, D.Sc., F.R.S., D. L. Phillips, M.Sc., and H. N. Jones, M.Sc.
"The Influence of Turbulence upon the Structure and Properties of Steel Ingots," by L. Northcott, D.Sc.,

Ph.D., F.I.C.

Saturday, 19th July, 1941: The Staffordshire Iron and Steel Institute.

Place and Time: Station Hotel, Dudley, at 3.30 P.M.

Chairman: Mr. G. R. Bashforth, President of the Staffordshire Iron and Steel Institute.

Papers:

"Non-Metallic Inclusions in Steel. Quantitative Evaluation.—Part I.", by W. H. Hatfield, D.Met., F.R.S., and G. W. Giles.

"Intercrystalline Cracking in Boiler Plates." A Report from the National Physical Laboratory. Presented by Dr. C. H. Desch, F.R.S.

Saturday, 26th July, 1941: The Newport and District Metallurgical Society.

Place and Time: The Newport Technical College, Newport, Mon., at 6.15 P.M.

Chairman: Mr. G. H. Latham, President of the Newport and District Metallurgical Society.

Lecture: Principal C. A. Edwards, D.Sc., F.R.S., gave a lecture based on the paper by himself, Mr. D. L. Phillips, M.Sc., and Mr. H. N. Jones, M.Sc., entitled "The Influence of some Special Elements upon the Strain-Ageing and Yield-Point Characteristics of Low-Carbon Steels."

Saturday, 4th October, 1941: The Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association.

Place and Time: Royal Victoria Station Hotel, Sheffield, at 2.30 р.м.

Chairman: Dr. W. H. Hatfield, F.R.S., President of the Sheffield Society of Engineers and Metallurgists and Vice-President of The Iron and Steel Institute.

Papers:

"Examination of a High-Sulphur Free-Cutting Steel Ingot," by E. Gregory, Ph.D., M.Sc., F.I.C., and J. H. Whiteley, F.I.C.

"The Thermal Relations between Ingot and Mould," by

T. F. Russell.

"The Formation and Properties of Martensite on the Surface of Rope Wire," by E. M. Trent, M.Met., PhD. "Note on the Resistance to Furnace Atmospheres of Heat-Resisting Steels," by A. G. Quarrell, Ph.D., F.Inst.P.

Wednesday, 8th October, 1941: The Manchester Metallurgical Society.

Place and Time: Engineer's Club, Albert Square, Manchester, аt 4.30 р.м.

Chairman: Dr. W. E. Alkins, President-Elect of the Manchester Metallurgical Society.

Papers:

"The Polishing of Cast-Iron Micro-Specimens and the Metallography of Graphite Flakes," by H. Morrogh.
"The Metallography of Inclusions in Cast Irons and Pig

Irons," by H. Morrogh.

Wednesday, 29th October, 1941: The Ebbw Vale Metallurgical Society, the Newport and District Metallurgical Society and the Swansea Technical College Metallurgical Society.

Place and Time: Rational Hall, Alexandra Street, Ebbw Vale, Mon., at 7 P.M.

Chairman: Mr. L. J. Davies.

Lecture: Principal C. A. Edwards, D.Sc., F.R.S., gave a lecture on "The Annealing of Mild Steel Sheets."

Monday, 15th December, 1941: The Cleveland Institution of Engineers.

Place and Time: The Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough, at 6.30 p.m.

Chairman: Mr. L. F. Wright, President of the Cleveland Institution of Engineers.

Paper:

The Practical Side of Blast-Furnace Management, with Especial Reference to South African Conditions," by R. R. F. Walton. (In the absence of the author the paper was presented by Mr. J. E. Holgate, to whom the thanks of the Council are due.)

Local Members of the Institute were invited to attend a Meeting of the Sheffield Metallurgical Association at the Sheffield Metallurgical Club, 198 West Street, Sheffield, on 17th June, 1941, at 7.30 p.m., when the papers submitted to the Institute by Dr. L. Northcott on "The Influence of Turbulence upon the Structure and Properties of Steel Ingots" and by Dr. E. M. Trent on "The Formation and Properties of Martensite on the Surface of Rope Wire" were presented for discussion.

In addition, the Institute took part in a meeting organised by the Coke Oven Managers' Association, the Institute of Fuel and the Institution of Gas Engineers at the Royal Victoria Station Hotel, Sheffield, on Wednesday, 25th February, 1942, when a paper on "The Future of Coke," by Captain J. G. Bennett, was presented. Mr. D. R. Wattleworth, President of the Coke Oven

Managers' Association, was in the Chair.

The meetings were well supported and the discussions interesting. The Council desire once again to put on record their thanks to the Presidents, Councils and Secretaries of the Local Societies, as well as to the authors of the papers.

Discussions on "Efficiency in the Use of Fuel."

At the request of the Mines Department of the Government, the Institute of Fuel, in conjunction with the Institute and other scientific and technical institutions, organised a series of public meetings in Belfast, Birmingham, Bristol, Glasgow, Leeds, London, Manchester and Sheffield, in order to provide opportunities for open discussion on the best ways and means of promoting the efficient

use of fuel and power in existing industrial plants under present

conditions and for making constructive suggestions.

The Institute assumed the chief responsibility for organising one of these meetings which was held in the Lecture Hall of the Sheffield Public Libraries on Monday, 16th February, 1942, at 3 P.M., and in which the following organisations collaborated:

The Coke-Oven Managers' Association.

The Glass Delegacy of the University of Sheffield. Institute of British Foundrymen, Sheffield Branch.

Institute of Chemistry, South Yorkshire Section.

Institute of Fuel.

Institute of Metals.

Institution of Electrical Engineers, Sheffield Branch.

Institution of Gas Engineers.

Institution of Mechanical Engineers, Yorkshire Branch.

Junior Institution of Engineers, Sheffield Section.

Midland Institute of Mining Engineers.

National Association of Clayworks Managers, Sheffield Branch.

Refractories Association of Great Britain.

Sheffield Metallurgical Association.

Sheffield Society of Engineers and Metallurgists.

Society of Glass Technology.

Dr. W. H. Hatfield, F.R.S. (Vice-President), took the Chair, and Dr. R. J. Sarjant, Mr. H. C. Armstrong and Mr. D. L. Wilson opened the discussion.

The Council wish to express their thanks to all who assisted in making this meeting a success, and particularly to Mr. E. J. Thackeray (Sheffield Society of Engineers and Metallurgists) who undertook the duties of Honorary Organising Secretary.

Publications.

Papers and Committee and Andrew Carnegie Research Reports.— Two volumes of the Journal were published during the year. These contained the following nine Committee Reports, one Andrew Carnegie Research Report and ten papers:

"Third Report of the Oxygen Sub-Committee." (Paper No. 5/1941 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Oxygen Sub-Committee)).

"Intercrystalline Cracking in Boiler Plates." A Report from the National

Physical Laboratory.

"A Co-operative Investigation of the Factors Influencing the Durability of the Roofs of Basic Open-Hearth Furnaces." A Report by the Open-Hearth Refractories Joint Panel.

J.H. Awbery: "A Note on the Theory of Quenching." (Paper No. 3/1941 of the Alloy Steels Research Committee (submitted by Dr. E. Griffiths, F.R.S., through the Thermal Treatment Sub-Committee)).

F. G. Barker, J. Convey and J. H. Oldfield: "The Application of

Spectrographic Methods to the Analysis of Segregates." (Paper

No. 7/1941 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Inclusions Sub-Committee)).

L. W. Bolton: "A Study of some of the Factors Affecting the Resistance of Cast Iron to Deflection under Load at High Temperatures." (Andrew Carnegie Research Report).

A. J. Bradley, F.R.S., and H. J. Goldschmidt: "An X-Ray Investi-

gation of Iron-Nickel-Chromium Alloys."

B. Chalmers and W. E. Hoare: "The Longitudinal Ridged Structure in the Tin Coating of Tinplate."

E. Gregory and J. H. Whiteley: "Examination of a High-Sulphur Free-Cutting Steel Ingot." (Paper No. 6/1941 of the Committee on the Heterogeneity of Steel Ingots).

T. P. HOAR, T. N. MORRIS, and W. B. ADAM: "The Influence of the Steel-Base Composition on the Rate of Formation of Hydrogen-

Swells in Canned-Fruit Tinplate Containers.—Part II."

T. LAND: "The Ladle Cooling of Liquid Steel." (Paper No. 1/1941 of the Steel Castings Research Committee (submitted by Mr. D. A. Oliver)).

H. Morrogh: "The Polishing of Cast-Iron Micro-Specimens and the Metallography of Graphite Flakes."

- H. Morrogh: "The Metallography of Inclusions in Cast Irons and Pig Irons."
- L. NORTHCOTT: "The Influence of Turbulence upon the Structure and Properties of Steel Ingots."
- A. G. QUARRELL: "Note on the Resistance to Furnace Atmospheres of Heat-Resisting Steels." (Paper No. 2/1941 of the Alloy Steels Research Committee).
- T. F. RUSSELL: "The Thermal Relations between Ingot and Mould." (Paper No. 4/1940 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Stresses in Moulds Panel of the Ingot Moulds Sub-Committee)).

T. SWINDEN and J. H. CHESTERS: "Dolomite Bricks for Use in Steel-

works."

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EWART S. TAYLERSON: "Atmospheric Exposure Tests on Copper-Bearing and Other Irons and Steels in the United States." (Paper No. 4/1940 of the Corrosion Committee (communicated by Dr. W. H. Hatfield, F.R.S.)).

E. M. TRENT: "The Formation and Properties of Martensite on the

Surface of Rope Wire."

J. H. Whiteley: "Apparent Relations between Manganese and Segregation in Steel Ingots." (Paper No. 8/1941 of the Committee on the Heterogeneity of Steel Ingots).

The Bulletin of The Iron and Steel Institute was published monthly during the year; as usual it was reprinted as Section II. of the Journals issued for the corresponding periods. The Bulletin is supplied free of charge to Members on application; the subscription rate to non-members is 30s. per annum (\$6 to members of the American Iron and Steel Institute, the American Institute of Mining and Metallurgical Engineers and the American Society for Metals).

Bibliographies.—The following bibliographies were prepared, and are included in the Bibliographical Series; copies are available at 2s. 6d. each (Members' rate 1s. 0d.).

No. 8A.—Bibliography on the Physical Chemistry of the Open-Hearth Process. (Covering the period 1938 to 1940.) (Supplement to No. 8.)

No. 9.—Bibliography on Grain Size in Steel (including Abnormality, Normality and Hardenability), with an Appendix, Bibliography on the Effect of Grain Size on the Magnetic Properties of Steel. (Covering the period 1922 to 1940.)

Translation Service.—Translations of thirty-three foreign technical papers were prepared and included in the Institute's Translation Series; they are obtainable by Members at 10s. each

(5s. for each additional copy of the same translation).

Members requiring translations of foreign technical papers are invited to communicate with the Secretary. Those that are suitable will be included in the Translation Series and will be supplied at the rates indicated above; it may be possible to prepare others at the Member's expense.

JOINT LIBRARY AND INFORMATION DEPARTMENT.

Joint Library.

Greater use was made of the Library by Industrial Companies and Government Departments as well as by Members of the Institute and of the Institute of Metals, and 5949 volumes were sent out on loan during 1941, as compared with the former record number of 4270 in 1940.

Many important text-books have been added and the Council wish to take this opportunity of thanking those who have made presentations to the Library. A list of the Additions made to the Library is issued quarterly, and copies will be sent to Members on request. German technical periodicals are again available for loan to Members and translations can be supplied.

The majority of the articles abstracted in the Bulletin of The Iron and Steel Institute are filed in the Library, and are available for loan. The original articles can be purchased for Members on request, and photographic copies can be supplied under certain conditions.

Collaboration with The Institution of Civil Engineers and the Science Library.

The valuable collections of scientific works included in the Science Library and the Library of The Institution of Civil Engineers are available for consultation or loan under certain conditions. Members who wish to avail themselves of these facilities should communicate with the Librarian of the Joint Library, 4 Grosvenor Gardens, London, S.W.1.

Information Department.

The Information Department has dealt with an increased number of enquiries, and bibliographies have been compiled at the request of Members. Members are invited to avail themselves of the bibliographical and information services.

RESEARCH.

Collaboration with the Iron and Steel Industrial Research

Council was continued on the same basis as in former years.

The following is a list of the Joint Committees of the Institute and the British Iron and Steel Federation, reporting to the Iron and Steel Industrial Research Council and of their Sub-Committees; the number of meetings recorded in 1941 was 64 (59 in 1940; 56 in 1939):

- Alloy Steels Research Committee: Chairman, Dr. W. H. Hatfield, F.R.S. Established June, 1934. Meetings held during 1941: five.
 - Thermal Treatment Sub-Committee: Chairman, Mr. P. B. Henshaw. Established January, 1936. Meetings held during 1941: one.
 - Hair-Line Crack Sub-Committee: Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1938. Meetings held during 1941; five.
 - Special Aero-Components Sub-Committee: Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1940. Meetings held during 1941: (not recorded).
- Corrosion Committee: Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1928. Meetings held during 1941: five.
 - Laboratory Research Sub-Committee: Chairman, Dr. U. R. Evans. Established June, 1930. Meetings held during 1941: two.
 - Protective Coatings Sub-Committee: Chairman, Mr. T. M. Herbert. Established January, 1936. Meetings held during 1941: two.
 - Marine Corrosion Sub-Committee: Chairman, Dr. G. D. Bengough, F.R.S. Re-formed November, 1938. Meetings held during 1941; six.
 - Sub-Committee on Low-Alloy Steels: Established June, 1938. No meetings held during 1941; activities carried on by correspondence.
 - Sub-Committee on the Corrosion of Buried Metals (working in collaboration with the Committee on Soil Corrosion of Metals and Cement Products of The Institution of Civil Engineers). Established October, 1937. No meetings held during 1941; activities carried on by correspondence.
- Heterogeneity of Steel Ingots Committee: Chairman, Dr. W. H. Hatfield, F.R.S. Established May, 1924. Meetings held during 1941: five.
 - Ingot Moulds Sub-Committee (joint with the Open-Hearth Committee of the Iron and Steel Industrial Research Council): Chairman, Mr. R. H. Myers. Established November, 1934. No meetings held during 1941; activities carried on by correspondence. (Stresses in Moulds Panel, activities carried on by correspondence.)
 - Joint Sub-Committee on the Physical Chemistry of Steelmaking (formed jointly by the Committee on the Heterogeneity of Steel Ingots and the Open-Hearth Committee of the Iron and Steel Industrial Research Council): Chairman, Dr. T. Swinden. Established September, 1938. Meetings held during 1941: one.

- Liquid Steel Temperature Sub-Committee: Chairman, Mr. E. W. Elcock. Established March, 1929. Meetings held during 1941: four.
- Oxygen Sub-Committee: Chairman, Dr. T. Swinden. Established January, 1936. Meetings held during 1941: one. (Chemists' Panel, two).
- Inclusions Sub-Committee: Chairman, Dr. W. H. Hatfield, F.R.S. Established November, 1936. Meetings held during 1941: five.
- Standard Methods of Analysis Sub-Committee: Chairman, Dr. E. Gregory. Established September, 1939. Meetings held during 1941: five.
- Steel Castings Research Committee: Chairman, Mr. W. J. Dawson. Established November, 1934. Meetings held during 1941: six.
 - Moulding Materials Sub-Committee: Chairman, Dr. W. J. Rees. Established March, 1936. Meetings held during 1941; five.
 - Foundry Practice Sub-Committee: Chairman, Mr. F. Cousans. Established May, 1938. Meetings held during 1941: four.
 - Foundry Steel Temperature Sub-Committee: Chairman, Mr. D. A. Oliver. Established December, 1941. No meetings held during 1941.

APPOINTMENT OF REPRESENTATIVES.

The following is a list of the Institute's representatives on various governing bodies and committees for the year 1941; it has been brought up to date to 31st March, 1942:

British Association, Fuel Economy Committee: appointment open.

British Cast Iron Research Association: Professor T. Turner.

BRITISH CORPORATION REGISTER OF SHIPPING AND AIRCRAFT, Technical Committee: Dr. A. McCance.

BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION,

Sub-Committee J/E, Joint Committee, Steels for High Temperatures: Dr. W. H. Hatfield, F.R.S., Dr. T. Swinden.

Sub-Committee J, Earthing to Water Mains: Dr. J. C. Hudson. British Iron and Steel Federation, Statistical Committee: Mr. K. Headlam-Morley.

British Refractories Research Association, Council: Mr. W. J. Brooke.

British Standards Institution,

Chemical Engineering Divisional Council: Mr. E. F. Law. Engineering Divisional Council E/-: The Hon. R. G. Lyttelton, Dr. T. Swinden and Mr. K. Headlam-Morley. Sub-Committee M33/7, Protective Glasses for Welders and

Industrial Purposes: Dr. C. H. Desch, F.R.S.

Technical Committee CEB/1, Cement: Mr. F. W. Harbord, C.B.E.

Technical Committee CEB/6/1, Concrete Blocks: Mr. F. W. Harbord, C.B.E.

Technical Committee CH/17, Symbols used in Diagrams of Chemical Engineering Plant: Mr. A. E. Chattin.

Technical Committee EL/28, Fans: Mr. A. F. Webber.

Iron and Steel Industry Committee IS/-: Dr. T. Swinden. Technical Committee IS/1, Co-ordination of Iron and Steel

Specifications: Dr. T. Swinden.

Technical Committee IS/6, Steel Castings: Dr. R. H. Greaves.

Technical Committee IS/8, Creep Properties: Dr. W. H. Hatfield, F.R.S.

Technical Committee IS/15, Iron and Steel for Shipbuilding: Sir Edward J. George.

Technical Committee IS/17, Cast Iron Columns for Street Lighting: Mr. J. G. Pearce.

Technical Committee IS/35, Cast Iron: appointment open. Technical Committee IS/35/3, Malleable Steel Castings: Mr. C. H. Kain.

Technical Committee ME/22, Marking and Colouring of Foundrymen's Patterns: Mr. F. W. Lewis.

Technical Čommittee ME/23, Brinell Hardness Testing: Dr. W. H. Hatfield, F.R.S.

Technical Committee ME/25, Testing of Thin Metal Sheet and Strip: Dr. T. Swinden.

Technical Committee ME/32, Engineering Symbols and Abbreviations: Dr. T. Swinden.

Solid Fuel Industry Committee, SF/-: Mr. A. F. Webber. Technical Committee SF/1, Nomenclature and Definitions: Mr. A. F. Webber.

Technical Committee SF/2, Underfed Screw Type Stokers: Mr. A. F. Webber.

Technical Committee SF/4, Heating Stoves: Mr. A. F. Webber.

Technical Committee on Metallic Finishes: Mr. F. C. Platt. Units and Technical Data Co-ordinating Committee: Sir Wm. Larke, K.B.E.

CITY AND GUILDS OF LONDON INSTITUTE, Advisory Committee on Metallurgy: Mr. E. C. Greig.

CONSTANTINE COLLEGE, Advisory Committee: Mr. E. W. Jackson. Empire Council of Mining and Metallurgical Institutions: Mr. F. W. Harbord, C.B.E., Mr. K. Headlam-Morley.

Engineering Public Relations Committee, Main Committee: Mr. James Henderson.

Executive Committee: Mr. K. Headlam-Morley.

Hong-Kong University, Home Committee: appointment open.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, Board of Governors: Mr. James Henderson.

IMPERIAL INSTITUTE, Mineral Resources Department, Iron and Ferro-Alloy Metals Committee: Mr. K. Headlam-Morley.

Institute of Fuel, Council: Dr. R. J. Sarjant.

Institute of Welding, Council and Representative of Patron Institution: Mr. K. Headlam-Morley.

Institution of Mechanical Engineers, Research Committee on High-Duty Cast Irons for General Engineering Purposes: Dr. J. E. Hurst.

IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL: Mr. F. W. Harbord, C.B.E., Dr. W. H. Hatfield, F.R.S., Mr. K. Headlam-Morley.

Joint Committee on Materials and their Testing: Mr. K.

Headlam-Morley.

LIVERPOOL UNIVERSITY, Court of Governors: Sir W. Peter Rylands, Bt.

LLOYD'S REGISTER OF SHIPPING, Technical Committee: Mr. James Henderson, Mr. P. Baxter.

NATIONAL PHYSICAL LABORATORY, General Board: Dr. T. Swinden, Dr. W. H. Hatfield, F.R.S.

Parliamentary and Scientific Committee: Mr. K. Headlam-Morley.

RAMSAY MEMORIAL LABORATORY, Advisory Committee: Mr. F. W. Harbord, C.B.E.

ROYAL SCHOOL OF MINES, Advisory Board: Mr. F. W. Harbord, C.B.E.

ROYAL SOCIETY, General Board for Administering Government Grants for Scientific Investigations: The President.

School of Metalliferous Mining (Cornwall), Board of Governors: Mr. J. S. Hollings.

Science Museum, Advisory Council: appointment open.

SHEFFIELD UNIVERSITY, Court of Governors: Mr. A. B. Winder.

STATEMENT OF ACCOUNTS FOR 1941

1942—i D

THE IRON AND

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STEEL INSTITUTE.

31st DECEMBER, 1941.

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Office Furniture and			***	***	***	• • •	•••				Not v	alu	ea.
Cash at Bank and in Secretary's Accoun								177	10	6			
Deposit Account .		***	***	• • •	***			55		4			
Deposit Post Office		 198 A	ccount	***			•••	245					
General Account .		-50	***					402		3			
		•••	***		***			42	0	2			
											923	7	2
Investments at Cost	per So	chedu	le :—										
General Fund (The Market valu 1941, was £29,				nents	at 31st	Dece	ember,				25,904	15	4
Toint Dogganah Comm	oitton												
Joint Research Comn Amount advanced	mutees										150	2	2
Life Composition Fur	br	***	***	004	•••						100	did	4
Investments at cos		Sched	ule								3,259	14	8
(The Market value 1941, was £3,4	ae of t	hese	Investr		at 31st	Dece	ember,						

£34,607 4 6

INCOME AND EXPENDITURE ACCOUNT

1940.		INCOME.						ı
£ 87 204	£	Entrance Fees 112 2 0 Do. Companies' Nominations 92 8 0	£		d.	£	8.	a
291	_	Less Transfer to Reserve Fund	204 204		0			
180 304 169	.653	Annual Subscriptions: Members, Home Current Do, Companies' Nominations Do, Arrears	4,566 94 383	10	6 0 3	5,044	19	
$\frac{413}{2}$ 123	,	Members, Overseas Current Do. Companies' Nominations Do. Arrears	$^{1,011}_{\ 36}_{\ 101}$		0 0 8	1,149		
188 26 2	,538	Associates, Current	211 21 13	15 0 2	0 0 6			
,534	216	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	440	2	5	245	17	
87 — 1	1,621	Bulletin	83 117	6 5	0	640	13	
,053 123 16		Interest on Investments (Gross) :— General Fund Life Composition Fund Bessemer Medal Fund	1,066 123 16	4 3 0	$\begin{smallmatrix}11\\2\\0\end{smallmatrix}$	1 905	0	
750	1,192 12 29	Interest on Deposit Account	750	0	0		8 16 10	
375 25		Contribution to Joint Library 400 0 0 0 Less Refund 50 0 0	350	0	0			
750	1,100	Iron and Steel Industrial Research Council;— Grant for Bulletin	750	0	0	1,100	0	
500 500	3,250	Grant for Secretarial Services Grant for Information Service	2,500 500	0	0	3,750	0	
	158	British Iron and Steel Corporation, Ltd., re distribution of Basic Refractories Andrew Carnegie Research Fund:—				100	0	
	38 2,917	Transfer in respect of Grants Balance, being excess of Expenditure over Income carried down				4,783		

£1	16,724	•		•	£18,067	15	8
£	£	Special Subscriptions :—	£	s. d.	£	8.	d.
3,462 1,571		Contributions receivable during 1941 Income Tax recoverable	2,905 1,481	$\begin{smallmatrix}8&0\\9&10\end{smallmatrix}$			
5,033	5,033	Less Legal Expenses	4,386	17 10 0 5		17	E
	0,000	Balance, being excess of Expenditure over In-			4,551	17	Ð
		come			751	10	7

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FOR THE YEAR ENDED 31st DECEMBER, 1941.

1940. EXPENDITURE.												
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255		War Bonus	435 6 0									
7,447 553		Less Contributions from Ministry of Supply and British Iron and Steel Corporation, Ltd 733 6 8 Do. Andrew Carnegie Research	7,871 16 0									
150		Do. Andrew Carnegie Research Fund										
	6,744		883 6 8	6,988 9 4								
	$\frac{51}{286}$	National Insurance Staff Superannuation Fund		6,988 9 4 54 12 2 306 14 4								
	1,200	Office Rent		1.200 0 0								
	439 805	Repairs and Decorations and A.R.P Cleaning, Heating, Lighting and Water		273 0 5 958 15 8								
	433 106	Cleaning, Heating, Lighting and Water Library Books Office Furniture		237 4 9 30 5 8								
	143	Annual Meeting		183 8 8								
	81	Autumn Meeting		10 5 5								
,385		Annual Meeting	1,419 5 2									
$\begin{array}{c} 16 \\ 153 \end{array}$		Postage	176 7 2									
228 66		Advance Copies : Printing	251 6 2									
381		Postage Bulletin: Printing	438 10 10									
93		Postage	$\begin{array}{cccccccccccccccccccccccccccccccccccc$									
	2,322			2,845 9 1								
	402 330	Stationery and Printing Postage and Receipt Stamps		538 15 3 422 8 7								
184		Travelling and Entertainment Expenses	$\begin{array}{cccccccccccccccccccccccccccccccccccc$									
	184			361 19 (
46	46	Insurance	86 5 10 236 8 0	322 13 10								
	43	Auditors' Fee for 1940		43 10 (
	198 179	Telephone Rental and Calls Office Disbursements and Sundry Expenses		158 18 9 133 12 3								
	51	Translation Service		329 12 6 1 10 6								
	$\begin{array}{c} 24 \\ 14 \end{array}$	Bessemer Gold Medal Blast Furnace Symposium		1 10								
		Grants:— British Electrical and Allied Industries Re-										
50 25		search Association British Refractories Research Association	$\begin{array}{cccccccccccccccccccccccccccccccccccc$									
		Joint Committee on Materials and their										
10 50		Testing	$\begin{array}{cccccccccccccccccccccccccccccccccccc$									
10		Mellor Memorial	$\begin{array}{cccccccccccccccccccccccccccccccccccc$									
_		Parliamentary and Scientific Committee Foundry Prize	10 10 0									
	145	Iron and Steel Industrial Research Council—		166 10								
	2,500	Grant		2,500 0 0								
4	16,724		3	£18,067 15 8								
£	£		£ s. d.	£ s. d								
	2,917	Balance brought down Transfer Reserve and Suspense Account:—		4,783 15								
500		Repairs and Decorations										
50 500		10-year Index Library Account	50 0 0									
	1.050	Library Account Bessemer Gold Medal	25 0 0	75 0								
	1,050	Companies' Nominations:— Entrance Fees	000	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,								
204		Entrance $F \in \mathbf{e}s$ \mathcal{L} Subscription Account :— \mathcal{L} s. d .	92 8 0									
304		Home Members 94 10 0										
26		Overseas Members 36 15 0 Associates 21 0 0										
			152 5 0	244 13								
	536	Balance, being Excess of Income over Expen-		211 10								
	530	diture for the year										
	£5,033			£5,103 8								

WILLIAMS PRIZE FUND.

BALANCE SHEET, 31sT DECEMBER, 1941.

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<i>a.</i>	-		
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ASSETS. #83.452 15s. 7d. 3½% Conversion Loan (at cost) ## # # # # # # # # # # # # # # # #	On Current Account Post Office Savings Account		
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LIABILITIES. (3pital Value representing Market value of £3,000 3½% Conversion Loan at 21st September. 1926, when Fund was manurated	Income and Expenditure Account: Balance as at 1st January, £ 1941. Add Excess of Income over 551 Frankling for the over	to 31st December, 1941	
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INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1941.

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INCOME.	::		
INC	Interest on 3½% Conversion Loan		

ANDREW CARNEGIE RESEARCH FUND. BALANCE SHEET, 31st DECEMBER, 1941.

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ASSETS.	(The Market value of these Investments at 31st December, 1941, was £33,248 10s. 0d.)	sount		Iron and Steel Industrial Research Council:— Loan Account	Amount due to General Fund		:
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	Grants Auditors' Fees	mount of Original Fund (\$100,000) Add Amounts since Capitalised	Add Surplus Income as at £ 8. d.	1st January, 1941 Excess of Income over	Expenditure for the year 942 9 11		
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	ants	unt	id S	E			
7	Grants Auditors' Fees	Amount of Original Fund (\$100,000 Add Amounts since Capitalised	Ac				

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1941.

	£ 8. d.	25 0 0						942 9 11	£1,194 5 5
The Contraction of the Contracti	EXPENDITURE.	Scholarship Grants	Printing Reports	Contribution to General Fund on account of Salaries	Sundries	Audit Fee	Balance, being excess of Income over Expenditure for the	year	
	INCOME.	Interest on Investments (Gross) 1,180 15 9	Interest on Deposit 7717 7	Balance of Grant written back (M. Tibor Ver's Account) 5 12 1					<u>£1,194</u> 5 5

THE IRON AND STEEL INSTITUTE.

SCHEDULE OF INVESTMENTS AT 31ST DECEMBER, 1941.

VALUES.
MARKET
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AND
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COST
VALUES,
NOMINAL
SHOWING

Cost Value.	£ 8. d	2,161 0 8 1,253 14 0	2,149 2 4 2,149 13 3	1,594 12 6	3,175 18 1	9,512 7 1,000 0 0	£25,904 15 4			1,254 17 (638 6		£3,259 14 8
Market Value, 31st December, 1941.	£ 8. d.	4-	18		16	$14,018 3 11 \\ 1,007 10 0$	£29,450 9 7		628 16 7 48 15 0	1,037 8 0 705 7 5	216 1 780 9	£3,416 18 0
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	GENERAL FUND OF THE INSTITUTE	: :	. : : :	: :	: :	Fund)			: :	33)		
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		War	Sg./6 Southern Railway 4% Debenture Stock London and North Eastern Railway 4% 2nd (Do. do. 4% 1st do. 2½% Consolidated Stock Buenos Avres Great Southern Railway 4% Debenture Stock	London and North Bastern Railway 3% Debenture Stock	% Funding Loan 1960–90 (transferred from Special Purposes Fund)			31 % Conversion Loan	London Passenger Transnort Board 44% "4 " Stock (July 1933)	3½% War Loan 4% Funding Loan 1960-90	
		000	Sou	2½% Bue	4% Lon	4°°°			30 C	S T C	8 2 2 4 0 8	
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Cost Value.		, o d	5 16	794 2 0		0,	01	က	10	ಸರ	0		00		250 0 0	£26,399 18 10
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		(Trust	3½% War Stock	Do	34 % Conversion Loan	3% Local Loans	India 34% Stock, 198	India 3% Stock, 1948	North Eastern Electr	Great Western Railway 4		Nort	Do.	Do	3% Savings Bonds, 1	
fominal Value.		£ 8. d.	897 14 11	0 0 000	0 21 2	227 9 4	300 0	560 4 0 570 4 0	0 0 002	0 0 000	0 0 000	> 0	0 0 000,00	> 0	>	
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WILLIAMS PRIZE FUND.

91 6 £3,694 (Trustees: Sir Wm. Larke, K.B.E., Mr. James Henderson, The Hon. R. G. Lyttelton.) * * * 34% Conversion Loan ... P. 3,452 15

BESSEMER MEDAL FUND.

(Trustees: Lord Airedale and Sir Francis Samuelson.) London Midland and Scottish Railway 4% Debenture Stock 0 400 0

Hon. Treasurer. (Signed) JAMES HENDERSON,

We have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. We have also verified the Balances at the Bankers and the Securities for the Investments shown above.

224 REGENT STREET, LONDON, W.1. 31st March, 1942.

41 P

Chartered Accountant.

(Signed) W. B. KEEN,

Secretary.

(Signed) K. HEADLAM-MORLEY,

:

Warket Value.

PRESIDENTIAL ADDRESS.

By James Henderson.

I HAVE found it difficult to choose a subject on which to address the Institute on this, the occasion of my accession to the high office of President. At this time there is the additional problem in that discretion must be used both as to what may be said and what

must not be published.

In view of my long association with our industry as practised in North Lincolnshire I may be able to put on record some useful statement as to the importance of that district in our national economy. Also, I am the first President of the Institute who has been directly connected with that part of the country. My remarks will be of a general character, but anyone who wishes to have full technical details will find much information in papers contributed to this Institute, to the Lincolnshire Iron and Steel Institute and elsewhere—a bibliography is appended.

I will conclude the Address with a résumé of the research activities of the industry, with the growth of which I have had

many contacts.

First, then, I need hardly remind you that the iron and steel industry of North Lincolnshire is based on the deposit of ironstone known as the Frodingham bed. This outcrops on a line running roughly north and south, about four miles east of the River Trent—the northern limit of the outcrop being about four miles south of the Humber, with a southern limit about ten miles further south. The bed dips east and south-east, and within two miles of the outcrop it is heavily overlaid by the Lincolnshire limestone and other strata. It is intersected by the west—east branch line of the London and North Eastern Railway, which runs from Doncaster to Grimsby and Immingham—thus providing access to the coalfields of South and West Yorkshire in one direction and to excellent shipping facilities in the other.

The deposit must have been known many centuries ago, as traces of primitive workings by the Romans are found, but it was not until the middle of last century that operations on a commercial scale were undertaken. The first blast-furnace was started up in 1862 at the Trent Iron Works. In the following twelve years other furnaces were built, all being of a simple character with the modest equipment of those times. The latest examples of that period were built in 1874 by the Appleby Iron Co., Ltd., which had

a capital of £50,000 for a four-furnace plant.

All of these furnaces made forge and foundry iron for sale, and, while handsome profits were sometimes realised, the financial returns were unsatisfactory as a general rule. Much credit is due

to Messrs. Cliff, the owners of the Frodingham Iron Co., in that they decided in the year 1888 to put down a steelmaking plant. They consulted Mr. Percy Gilchrist, who advised them to adopt the basic open-hearth process, then in its experimental stages. He secured for them the services of Mr. M. Mannaberg, and steelmaking actually began at the Works of the Frodingham Iron & Steel Co., Ltd., in 1890. Mr. Mannaberg had all the qualities of a pioneer enterprise, energy and confidence. Overcoming many difficulties, both technical and commercial, he built up a prosperous industry, and it is without question due to him in the first place that the district has grown to its present importance. In 1912 the Frodingham Company, in association with The Steel Company of Scotland, Ltd., bought the Appleby Iron Co., Ltd., to form the basis of a new steelmaking plant; and in 1917 The United Steel Companies, Ltd., acquired both the Frodingham and the Appleby Companies. two were later merged to form the present Appleby-Frodingham Steel Co., Ltd. The Frodingham Works are equipped for the manufacture of sections, joists and such like, and the Appleby Works for plates.

In 1912 Messrs. John Lysaght, Ltd., set to work a completely new and well planned plant for the manufacture of coke, pig iron and steel, with mills for rolling sheet bars and billets. Originally of ordinary qualities, these are now made in highly specialised and alloy grades. Fuel economy has been brought to a very high point

of efficiency.

About 1916 the blast-furnace plant of the Redbourn Hill Coal and Iron Co., Ltd., which was one of the early plants, was acquired by Messrs. Richard Thomas & Co., Ltd., who erected coke-ovens, steel furnaces and rolling mills for billets, sheet and tinplate bars. In 1938 large reconstructions and extensions were made, effecting a greatly increased production and efficiency. A subsidiary company, The Whitehead-Thomas Bar & Strip Co., Ltd., have a modern bar mill.

There is also a steel foundry owned by Messrs. Thos. Firth &

John Brown, Ltd.

These concerns form a compact and neighbourly district. Their separate and combined output of coke, pig iron, steel ingots and rolled products cannot be stated at the present time, but it is considerable. Steel ingot production before the war was in the region of 1,300,000 tons per annum.

Three of the early plants which made pig iron only have been

liquidated and completely dismantled at various dates.

As already stated, the Frodingham ore bed is the foundation of the district's industry, and its characteristics deserve some attention. It is now being worked in open quarries, but in a few years an increasing proportion of the requirements must be got from underground. It is a definitely low-grade ore, the average content of iron being under 23%. It is probably the leanest ore in the world

being successfully smelted. As a whole it contains an excess of lime over silica, and a silicious ore must be brought in to secure a fluxing mixture. Ore from the Northamptonshire bed is commonly used. While the local ore is cheaply won by modern methods and machinery, its variable composition has presented through the whole history of the district very serious technical problems. To appreciate this difficulty the following figures are helpful: A vertical cut can have layers of ore varying from 14% to 26% of iron, 4% to 25% of silica and 4% to 35% of lime (CaO). Also two places in a quarry face, say, 1000 yards apart can have average analyses of vertical cuts varying between 18% and 24% of iron, 4% and 7% of silica and 20% and 27% of lime. In general, the mines management and the blast-furnace control are in continuous contact, affording all possible advance information of the character of the supplies coming forward from time to time. Excellent results have been obtained in this way, but there has been a constant striving for more reliable and error-proof methods. Very successful results have been achieved in recent years at the South Works of the Appleby-Frodingham Company. Extensive and costly plant has been erected, in which the ore as it comes from the quarries is crushed in two operations to a size not over $2\frac{1}{2}$ in. Screening takes place at various stages, and the fines go to form part of a sinter mixture. Northamptonshire ore is crushed, dried and screened, the fines again going to the sinter plant, where a mixture of all fines, along with the blast-furnace flue dust and coke screenings, is sintered in a Dwight-Lloyd plant to form a product of reasonable regularity and mechanical condition.

The larger sizes of the ores coming from the crushing plant are taken to a "bedding" plant, where layer after layer is spread horizontally on a prepared floor and built up in an elongated pyramidal heap to a convenient height. The mixture is removed by vertical cuts and conveyed by belt to the blast-furnace bins. The resulting product is regular in composition to a surprising degree. This plant is unique in the world as applied to blast-furnace

The effect of this ore preparation is remarkable in obtaining increased output from the furnace and lower coke consumption. Coke used averages about $21\frac{1}{2}$ cwt. per ton of pig iron in the newest large furnaces with an ore mixture of about 68 cwt. per ton (no limestone is required for reasons previously explained). Other furnaces in the district operating without these facilities consume 26 to 30 cwt. of coke per ton of iron.

In the present times, when economy in fuel is of such great national importance, it is most unfortunate that an extension of such bedding practice is hardly possible for obvious reasons.

To summarise, the district owes its existence to low-cost pig iron, based on local ores having at present a unit of iron value of about $2 \cdot 3d$. per ton, Northamptonshire ore 3d. per ton-unit and

a reasonably priced coke obtained either in the district or from coke-ovens on the coal fields which are 30 to 50 miles distant. These advantages, combined with excellent furnace practice, result

in pig iron which has one of the world's lowest costs.

While these advances in blast-furnace technique have been taking place, great improvements in open-hearth steelmaking have also been made. Generally, furnaces are heated by a mixture of blast-furnace and coke-oven gases. All the works employ fixed or tilting furnaces fed with liquid metal, some with only such scrap as is produced within the works; others supplement this with moderate amounts from outside. Furnaces vary considerably in size and type, but the Appleby-Frodingham Company have developed as standard practice tilting furnaces of 250 to 300 tons capacity, working a process based on the Talbot continuous method. Outputs average 1800 to 2000 tons per week with a high thermal efficiency.

Rolling-mill practice in the district is reasonably good. The mills at the Appleby plant are an outstanding example of modern plate-mill practice, both as to layout and equipment; very full

details can be found in the reference appended.

Progress at the Lincolnshire works such as I have briefly described would not have been possible without research. Research in a steel company is not an end in itself. It should not be directed to the increase of knowledge merely for the sake of increasing knowledge; it should rather be directed by the practical desire to improve the quality of the product and profitably to modify the processes of manufacture—as an example, to make as cheaply as possible a steel ingot or bar suitable for the purpose intended and of improved functional quality. This conception does not limit the field open to research workers employed in the iron and steel industry; it merely sets a goal to their endeavours. There is open to them, indeed, a virtually limitless field of activity, and naturally they should be qualified to derive assistance from the latest developments of science.

Dealing first with research within individual companies, I am glad to put it on record that very considerable strides have been made in recent years in building up staffs and laboratories for research. Every leading steelmaker in the country has, in addition to laboratories dealing with routine analyses and local problems, an organisation for the study of major problems and the development of new and improved products. These central research laboratories are in constant touch with the works and with works problems; they are very much concerned with production problems, and the value of their work would be greatly reduced if they were interested only in theory and pure science. On the other hand, the production staff at the works maintain close contact with the central laboratories, and most problems of importance are thrashed out jointly. To summarise, constant attention must be given by all responsible

officials at works to details in the technique of production. At the same time there must be keenness to experiment and the courage to risk failure by trying something new. There must also be constant endeavour to satisfy the customer, and sometimes even in a tactful way to educate him-and not least under present circumstances, when more often than not the customer is a Government Department. The old adage that the customer is always right was certainly not invented by a steelmaker. All these various activities may be included as research; none of them can be excluded with impunity by those responsible for the management of a great modern steelworks.

I have noticed in recent years a growing tendency to distinguish between research into processes and research into products; or, again, between activities which are variously referred to as practical. short-range research or technical development, and activities which are dignified by the title of fundamental, scientific or long-range research. The former are supposed to form the useful occupation of hard-working officials engaged on production and their technical staff: the latter are said to be the sphere of illustrious scientists

working in purely academic surroundings.

With this view I profoundly disagree. It is utterly opposed to the spirit which has invigorated this Institute from its foundation. Nothing could be further removed from the conception of those great men to whom the iron and steel industry of the world owes so much and whose names are among those inscribed in the list of Bessemer Medallists in the entrance hall of this building—Bessemer himself, Lowthian Bell, Siemens, Thomas and Gilchrist and, in more recent times, Hadfield and Talbot, who is now one of our Senior Past-Presidents.

Mr. Mannaberg's name does not appear in that list, although surely his services to the industry in Lincolnshire, to which I have already paid tribute, and to the country as a whole amply entitle him to this recognition, and I would recall also that it was largely due to his initiative that the Fuel Department of the British Iron and Steel Federation was set up, which, under the direction of Sir William Larke, has developed into the present-day Technical Department. None of these men drew hard and fast lines between research and practice and between development and operation.

Holding this opinion, it will be appreciated that I regard the present set-up of co-operative research in this country by the

existing organisations as being transitional.

At present, collective research by the steel industry is carried out by Research Committees responsible to the Iron and Steel Industrial Research Council. A majority of this Council is composed of representatives of the industry and the secretariat is provided by the Federation. It forms part of the organisation set up by the Government through the Department of Scientific and Industrial Research during the last war, and is indebted to that Department not only for generous financial support but also for the

helpful guidance of its representatives.

The Committees working under the Research Council are known to most of you, and their membership is drawn almost exclusively from Members of this Institute. A number of the Committees, especially those dealing with works operations, are serviced by the Technical Department of the Federation, and owe much to the enthusiasm of the Federation's officials. There are also some twenty Committees and Sub-Committees which look to the Institute secretariat for this assistance; these deal with such problems as are of a more fundamental character. But in all cases where useful work is being done, this is largely due to the enthusiasm of the Members, who are generally the works officials especially concerned with the problems under investigation, or members of their research staffs. It is this constitution of the Research Committees that forms a unique feature in the collective research activities of the iron and steel industry. No praise can be too high for the enthusiasm and sacrifice of time which Members of these Committees have brought to their collective deliberations. Not only is their knowledge put at the unfettered disposal of the problems under consideration, but the results obtained from these deliberations are at once available for use in the works. It should be borne in mind that the industry maintains no large central laboratories for the prosecution of research and that such experiments as the Committees wish to put in hand are carried out either in works and works laboratories or in such collaborating organisations as the National Physical Laboratory and the Technical Universities.

The division of research roughly into technical and fundamental problems is due, in my opinion, to historical accident rather than to any true functional division. After many years' association with the Research Committees of the Federation and of the Institute I consider that while the present arrangements may offer certain advantages, there would be much gained by a complete fusion of these parallel activities. The problem deserves, and should receive, the most careful study so that we may continue to encourage the development of invention and technique. We must see to it that the rising generation is fully equipped to carry forward the work begun by the great men of Britain whose names have already been mentioned and who placed our country in the forefront of world

progress.

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INVESTIGATION OF THE BEHAVIOUR OF METALS UNDER DEFORMATION AT HIGH TEMPERATURES.

PART II.—STRUCTURAL CHANGES IN CARBON STEELS CAUSED BY CREEP AND GRAPHITISATION.*

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(Figs. 4 to 64 = Plates I. to XII.)

SUMMARY.

A study was made of the behaviour of carbon steels by means of the microscopical examination of test specimens from short-time (tensile) and long-time creep tests. The specimens were tested in a high vacuum over the temperature range 15-950° C. In the majority of cases the stress applied was sufficient to cause rupture. The materials examined had various carbon contents up to 1.14%.

The effect of the carbon content was most noticeable in short-time (tensile) tests, but as the temperature of test was increased this effect was reduced. In creep tests at a temperature of 450° C. there was a marked difference in the life of the specimens of certain materials, those of high carbon content showing the greatest strength. At 550° C. and above, the effect of this element on the life in creep tests was not very noticeable. The α - γ structural change in iron and low-carbon steels between 700° and 900° C. caused a marked increase in the strength of the material as measured by short-time (tensile) tests, but in high-carbon steels there was little alteration in properties resulting from this structural change.

The work shows the general weakening of the material with increase of temperature and describes the nature of the structural changes set up. The deformed material gave evidence of slip and dislocation as well as recrystallisation, spheroidisation, graphitisation and cracking. The various materials showed these effects to varying

degrees, depending on their chemical compositions.

The deformation of ferrite occurred by the well-known action of slip, but a new mode of deformation is described in regard to the constituent pearlite. This is referred to as dislocation. It appears that the pearlite can be deformed by a shearing action on a plane

inclined to the ferrite and carbide lamellæ of the pearlite.

The tests were made principally on high-carbon steels in which recrystallisation of the ferrite was not so prominent a factor in their deformation as in the low-carbon steels described in an earlier paper. On account of the higher proportion of pearlite in these high-carbon steels spheroidisation was an important feature. In certain cases rapid spheroidisation was seen even in short-time (tensile) tests, on account of the accelerating influence of deformation. Spheroidisation might occur very locally in a test specimen, and this gave rise to appreciable softening and a sudden fracture of the specimen. The

reduction of area was relatively high, considering the degree of

elongation in these cases.

Graphitisation, which needs a longer time than spheroidisation to make its appearance, was also of common occurrence in high-carbon materials, particularly below the critical range (A_1-A_3) . The formation of graphite was found in the highly deformed material near the fracture in creep tests at a temperature as low as 450° C. The graphitic areas so formed acted as centres of weakness at which cracks developed in stressed specimens. Graphitisation was less pronounced above the A_1-A_3 range than below, occurring only in the steels of highest carbon content. It appeared to assist the development of intercrystalline cracking, which was observed above this range. The present work shows that steels referred to as rapidly graphitising offer, in general, a poor resistance to creep and spheroidise rapidly.

I.—Introduction.

This investigation forms a continuation of previous work on the structural changes in mild steel and commercial irons during creep. (1) The general object of the research as a whole is to correlate the structure and constitution of alloys with their behaviour at high temperatures.

In the present work a study was made of the mode of deformation and fracture of various normalised carbon steels in tensile and creep tests made over a considerable range of stress and with temperatures varying from 15° C. to 950° C. The behaviour of the materials was thus studied in both the ferritic and the austenitic

conditions.

This study is not primarily concerned with the measurement of creep strength for design purposes. This problem has recently been the subject of a paper $^{(4)}$ entitled "The Properties of Steels as a Basis for Design for High-Temperature Service." For design purposes in steels containing $0\cdot 10-0\cdot 40\,\%$ of carbon a total extension of $1\,\%$ is regarded as considerable, but in the present experimental work a deformation of as low as $1\,\%$ is found to have little accelerating influence on the changes in microstructure which proceed on exposure of the steels to high temperature. The rates of straining of test-pieces were high enough to bring about rupture of the majority of the specimens in under 2000 hr. These rates are appreciably higher than those adopted in design data, but are of the same order as those relating to the parts of equipment which fail in service by accidentally onerous conditions.

The temperature range of this work is far greater than would be obtainable in tests made in air on account of appreciable oxidation commencing at about 450° C. By undertaking the work in testing units working at high vacuum, the polished surfaces of the specimens were preserved against tarnish and surface or deep-seated attack

by oxidation.

In some of the tests graphite diffused to the surface of testpieces. Such a process would constitute a mechanism for the slow decarburisation of the steel. If such materials had been exposed to the slightly oxidising conditions such as occur in a poor vacuum, oxidation would have prevented the formation of graphite.

II.—STEELS EXAMINED.

In the earlier work already referred to $^{(1)}$ the following materials were studied: Two mild steels, two Swedish (Lancashire) irons, two ingot irons and a sample of unmelted carbonyl iron. These ranged in carbon content from 0.24% to 0.015%, respectively, and where necessary reference is given to the properties of the irons and steels described in the earlier paper. Some further tests described here were carried out on these materials. Steel M, one of the two mild steels referred to above, was made in a Siemens-Martin furnace. It was described by the manufacturer as an "acid steel, best quality," and was supplied in the form of 1-in. dia. rolled bars, normalised before delivery. The other, referred to as NGK, was commercially produced in a basic-lined furnace and was supplied in the form of 1-in. dia. rolled bar.

In the present work a detailed study was made of seven steels ranging in carbon content from 0.40% to 1.14%. Six of these steels, marked DA, DB, DC, NKS, NKE and NKT, were obtained in crucible-steel quality in the form of hot-rolled bar $\frac{3}{4}$ in. in dia. The seventh steel, GBE,* was produced in an acid open-hearth furnace and was deoxidised with ferro-silicon and ferro-manganese.

It was supplied in the form of plates 1 in. in thickness.

In undertaking a comparison of a series of steels, it is recognised that in certain temperature ranges some steels may be inherently weaker and some stronger than other casts of similar composition. In order to obtain a correct impression of the strength of steel of a particular composition it is therefore necessary to examine a large number of different casts of steel over a wide range of temperature. The nature of the changes in behaviour as seen by the microscope is fortunately similar for a number of steels differing somewhat widely in carbon content and properties, but the speed at which internal changes take place may be very different.

The analyses of the materials used are set forth in Table I., in which the results of the vacuum fusion (carbon reduction) estimation for nitrogen and hydrogen in steels M and NGK are given for the first time. Three of the steels, NKS, NKE and NKT, have a relatively high ratio of silicon to manganese. These steels were found to graphitise fairly readily, whereas steels DA, DB and DC have almost the same carbon contents as the three just mentioned, but the higher ratio of manganese to silicon has increased their stability. The formation of graphite, as is mentioned later, plays an important part in reducing the strength of high-carbon steels at high temperatures.

In order to maintain uniformity with the previous paper, the

^{*} See Section IV. (b) for reference to previous work on this steel.

Table I.—Composition of the Materials Used.

	NKT.		1.14 0.15	0.030	S II I	0.016 Trace	0.008 0.0035 0.000031		×	×	××	< i	A	A	×	ı	1	Д
	DC.		0.08	0.022		0.005 N:1	0.0052 0.0024 0.000024		×	×	××	<	A	D	×	ı	1	A
	NKE.		0.86	0.027		0.02 Trace	$\begin{bmatrix} 0.0046 \\ 0.0048 \\ 0.000127 \end{bmatrix}$		×	×	××	< 1	P	Q	×	1	1	D ·
	DB.	-	0.90	0.021		0-013 Nil	0.0054 0.0036 0.000015		××	×	××	< 1	D	Q	×	1	L	Ω
-	NKS.	.83	0.60	0.025	Trace	0.024 Trace		ation.	××	×	× > × >	< ! < !	Q	Д	×	1	1	А
,	DA.	a) Chemical Analysis.	0.57	0.022		0.005 Nil		Spectroscopic Examination.	×	×	×	1	Q	Д	×	-	L	Д
'	GBE.	(a) Chemi	0.21	0.035	0.025	Trace		Spectroscop	×	×	××	<	Q	Q	×	1	H	Q
	NGK.	_	0.05	0.016	Trace	0.09 Trace	0.0029 0.022 0.000063	(q)	×	:	××		Ω.	Э	×	:	:	:
	M.	_	0.17	0.025	0.061 Nii	0.044 Trace	0.007 0.005 0.000036		×		× ×		<u>.</u> A	А	×	:	:	:
			• • •							٠							٠	
			• • •								•			٠	٠			
				%	0 . %	.%	* % %						 d		•			
			Carbon. Silicon.	Phosphorus.	Nickel. % Chromium.	Copper. %	By vacuum Nitrogen. Oxygen. Hydrogen		Aluminium	Tin .	Calcium .	Tungsten	Molybdenun	Titanium	Barium .	Arsenic .	Boron .	Cerium .

* The nitrogen values given in the earlier paper for some of these steels had been determined by a chemical method. - = element probably absent; \times = very faint trace; $\times \times$ = faint trace; $\times \times$ = heavier trace; D = doubtful.

spectroscopic analyses of the steels have been recorded in Table I. in the same form as in Table I. of the previous paper. (1) The notation expresses the relative proportions of any one element present in a number of steels in a manner which allows qualitative comparison. The mode of expression is not intended to provide a comparison of the quantities of various elements in an individual steel.

Macroscopic examination of longitudinal and transverse sections of the steels did not show any appreciable degree of segregation of the sulphur and phosphorus contents. There was probably a slight increase in the number of non-metallic inclusions locally in one or two materials, but this feature was not regularly present in all the bars.

Steels DA, DB and DC presented difficulty in normalising, owing to their high manganese contents. Double normalising treatments were applied to these three steels, and these gave greater uniformity of structure and of grain size. The specimens the microstructures of which are shown in Figs. 44 and 61 were, however,

given a single normalising treatment.

A comparison of the microstructures of steels NGK, GBE, DA and NKS (see Figs. 5 to 8) shows that the rise in carbon content increases the proportion of pearlite and, in a normal manner, decreases that of the free ferrite. Steels DB and NKE (see Figs. 9 and 10) are mainly pearlitic, but the pearlite in steel NKE is often coarsely distributed and locally the lamellar form of the eutectoid tends to disappear. Steels DC and NKT (see Figs. 11 and 12) consist principally of pearlite, but contain an appreciable amount of free cementite distributed either in an idiomorphic form or separated as thick intergranular films. Some of the steels examined have a coarse grain size, but possess a slightly banded form of segregation of the ferrite and pearlite.

III.—Conditions of Testing.

The methods of test and examination were similar to those adopted in the earlier work (1) on low-carbon steel and iron. The bars were first normalised and then machined to size under conditions which reduced the surface distortion to a minimum. They were then polished on the parallel portion and etched for microscopical examination before testing.

The diameter of the standard specimen was 0.357 in. If a higher load than 10 tons per sq. in. was desired the diameter was further reduced to 0.282 in. or 0.226 in. The gauge length was

equal to $4\sqrt{\text{area.}}$

The creep-testing units, shown in Figs. 1 and 2 of the earlier paper, have now been increased in number from three to six. Some of these are shown in Fig. 4. The mode of loading these units has been described recently in greater detail in a paper on "The Auto-

matic Maintenance of Load in Creep Testing." (2) Readings were taken during the course of the tests of the total elongation of the specimen between the shackles. These readings gave an indication of the shape of the elongation-time curve. Measurements of the total extension and reduction of area of the test-piece were taken after its removal from the testing unit. Tensile tests were also made in the unit which was designed for use in the Amsler testing machine (see Fig. 3 of the previous paper). Although short-time (tensile) tests are of secondary value in an assessment of the general behaviour of a material at high temperatures, it is not desirable to dispense with these tests, as microscopical examination of the tested specimens shows that useful information can be derived from them and that such tests are a useful guide to the initial planning of longer-time tests.

The rate of straining in the Amsler machine can be indicated by the time taken to bring about rupture in the various specimens. A constant setting was used on the control valve of the pressure-oil supply, and this meant that 3-4 min. were required to extend 30-60% and 5-6 min. for 100-120%. The specimens were heated in the furnace and were tested as soon as they attained the testing

temperature.

All the tensile tests at 750° C. were carried out on the normalised steels without previous heating to a higher temperature. (The majority of the specimens used for creep tests at 750° C. were heated to 800° C.) The steels used in the tensile tests had not formed any γ -iron at 750° C.

A description of the method of mounting specimens for microscopical examination in a coating of electrolytically deposited iron, referred to in the earlier paper, has now been given in detail recently. (3)

IV.—RESULTS OF TENSILE AND CREEP TESTS.

(a) Short-Time (Tensile) Tests on High-Carbon Steels.

Tensile tests were carried out at room temperature, 250° and 350° C. in air and in vacuum at intervals of 100° from 450° to 950° C. on the materials, with the exception of NKE, NKS and NKT. The properties of the steels at room temperature are given in Table II. and at elevated temperatures in Table III. Some of the data from the latter Table are plotted in Figs. 1 and 2, and in addition information on certain materials, namely, carbonyl iron C (0·015% of carbon) and steels NGK (0·24% of carbon) and M (0·17% of carbon) is plotted from the results contained in the previous paper. A comparison at 950° C. of steel DB with certain materials of low carbon content is contained in Section IV. (d).

(i) The Effect of Temperature on the Tensile Strength.—The results indicate that all the steels exhibit a maximum tensile strength in the neighbourhood of 200–350° C. This increase in tensile strength above the room-temperature value is probably the result of ap-

Table II.—Mechanical Properties of Materials at Room Temperature (15° C.).

				, .			
Mater-	Carbon Con- tent. %	Heat Treatment.	ment. Brinell Hardness P Number, $L/D^3 = 10$.		Ultimate Tensile Strength. Tons per sq. in.	Elonga- tion. %.	Reduction of Area.
GBE	0.40	15 min., 900° C., A.C.	169 177 }	22.1	39.0	83	53
DA	0.57	15 min., 950° C., A.C., and 15 min., 875° C., A.O.	208 207	26-9	46-6	26	41
NKS	0.60	15 min., 850° C., A.C.	185 184	24·5 24·1	42·4 42·2	28 31	23 25
DB	0.90	15 min., 900° C., A.C., and 15 min., 850° C., A.C.	$\left\{ \begin{array}{c} 270 \\ 272 \end{array} \right\}$	31-9	64-4	14	20
NKE	0.86	15 min., 790° C., A.C.	203 199	21·7 23·2	50·5 56·0	16 14	15 12
DC	1.10	15 min., 950° C., A.C., and 15 min., 900° C., A.C.	257 260 }	32-5	58-2	9*	11
NKT	1.14	15 min., 900° C., A.C.	282 276 }	30-3	57-4	13	20

^{*} Broke outside gauge length.

Table III.—Short-Time Tensile Tests at Various Temperatures.

Temp.	Material:	GBE.	DA.	DB.	DC.
	Carbon Content, %:	0·40	0.57	0.90	1·10
Room Temp., 15	Yield point. Tons per sq. in. Ult. tensile strength. Tons per sq. in. Elongation. % Reduction of area. %	22·2 39 33 53	26.9 46.6 26 41	31·9 64·4 14 20	32·5 58·2 9* 11
250	Yield point. Tons per sq. in. Ult. tensile strength. Tons per sq. in. Elongation. % Reduction of area. %	19·3 41·0 19 41	23 52·5 18 24	63.6 10.5 18	63·0 7·5* 13
350	Ult. tensile strength. Tons per sq. in. Elongation. % (Reduction of area. %	40·8 23 51	45·2 38 58	54·4 34 61	57·9 16·5 27
450	Ult. tensile strength. Tons per sq. in.	31·0	34·4	39·1	44·0
	Elongation. %	36	28	38	25
	Reduction of area. %	58	68	77	45
550	Ult. tensile strength. Tons per sq. in.	21·7	23·4	25·9	30·5
	Elongation. %	34	54	46	34
	Reduction of area. %	62	88	83	50
650	Ult. tensile strength. Tons per sq. in.	11·2	13·3	18·7	15·0
	Elongation. %	57	75	60	77
	Reduction of area. %	95	96	82	69
750	Ult, tensile strength. Tons per sq. in.	5·3	6·8	7·1	8·7
	Elongation, %	118	116	77	160
	Reduction of area. %	98	97·5	99	95
850	Ult. tensile strength. Tons per sq. in.	4·1	4·3	4·3	4·1
	Elongation. %	119	82	84	84
	Reduction of area. %	>99	>99	>99	>99
950	Ult. tensile strength. Tons per sq. in. Elongation. % Reduction of area. %	2·77 97 >99	2.58 94 >99	2·33 82 >99	$\begin{vmatrix} 2.17 \\ 125 \\ > 99 \end{vmatrix}$

^{*} Broke outside gauge length.

preciable hardening by ageing during the course of the test. Above $200-350^{\circ}$ C. a continuous fall in strength occurs until the region is reached where the $\alpha \rightarrow \gamma$ transformation begins. In the high-carbon steels this is at about 750° C. and at higher temperatures in

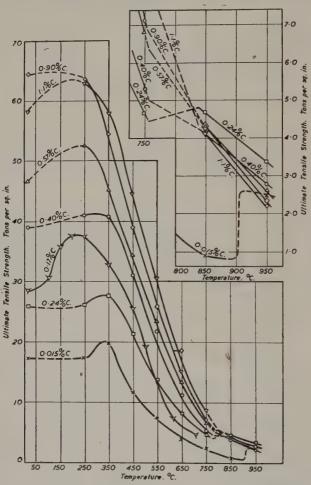


Fig. 1.—Short-Time (Tensile) Tests on Carbon Steels.

materials containing 0.24% or less of carbon, being above 900° C. in the case of the carbonyl iron. The rise in strength at the transformation point is quite marked in the carbon steels below 0.40%, but there is little change in strength in steels of higher carbon content. As

mentioned in the previous paper, ⁽¹⁾ the change in the lattice structure of iron at a temperature slightly higher than 900° C. is important. It will be remembered that an increase in the tensile strength at the A_3 point was described by Rosenhain and Humfrey ⁽⁵⁾ in regard to a sample of mild steel.

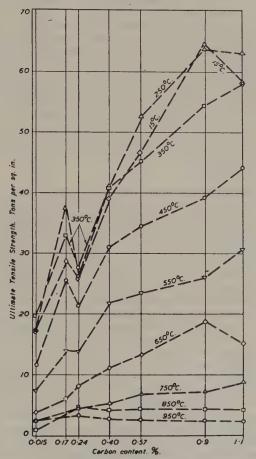


Fig. 2.—Short-Time (Tensile) Tests on Carbon Steels.

(ii) The Effect of Carbon Content on the Tensile Strength.—A reference to Table III. shows that in short-time (tensile) tests the presence of carbon brings about a general increase in tensile strength in the α range. The curves in Fig. 2 demonstrate that the steels exhibit at all temperatures up to 650° C. a steady increase in

strength until the eutectoid composition is reached at about 0.9% of carbon

At temperatures up to and including 450° C. the 0.24% carbon steel (NGK) is weaker than either the 0.17% or the 0.40% carbon steels (M and GBE) as far as the experimental data are known. At 650° C, the order of strength of the steels given in Fig. 1 is directly

related to the carbon content.

The results in Table III. relating to the tests at 850° and 950° C. show that an increase in carbon content does not greatly alter the strength of the steels which are in the γ state. The results at 950° C. even suggest a fall in strength with rise of carbon content. At a later date it might be of theoretical interest to carry out tests at an even higher temperature than 950° C. to ascertain whether an increase of the proportion of carbon alters the strength. While considering this point it should be noticed that at a given temperature of test, steels of higher carbon content are nearer to their melting temperatures than those of lower carbon content, and there is therefore a possibility that they are weakened by relative proximity to the melting point.

(b) Creep Tests on High-Carbon Steels.

In the previous paper it was stated that "steels of higher carbon content are not superior in creep resistance to the mild steels mentioned. This fact is of importance, for it is well known that at room temperature an increase in the carbon content results in increased strength." The mild steels discussed contained 0.17% and 0.24% of carbon and are referred to as M and NGK respectively in this paper. The properties of the carbonyl iron C (0.015% of carbon) discussed in the previous paper are also mentioned.

In this work the relative strengths of steels at various temperatures are compared by the time required to rupture specimens tested under similar testing conditions. The results of the creep tests where they form a series are given in Table IV., and some of the data from that source are plotted in Fig. 3 to show the relationship of specimen life to carbon content. In addition, many other tests have been made which are not set forth in Table IV.; some of these, which are referred to in this paper, indicate that when tests are carried out at different stresses, the relative behaviour of the various steels (life of specimen, degree of spheroidisation or of graphitisation, &c.) is found to alter.

In order to show the incidence of creep in a steel of eutectoid composition, two creep tests were made under a load of 40 tons per sq. in. on steel DB (0.90% of carbon) at temperatures of 350° and 400° C. The specimen tested at 350° C. broke after 3240 hr. with an elongation of 23% and a reduction of area of 37%, while that at 400° C. ruptured in as little as 60 hr. with an extension of 7% and a reduction of area of 39% (the latter specimen broke

outside the gauge length).

The tests at 450° C. made under a load of 16 tons per sq. in. show that the alloys DB and DC, containing 0.9% and 1.10%, of carbon, are undoubtedly stronger than those containing less carbon. The rapidly graphitising steel NKE (0.86% of carbon) is, however,

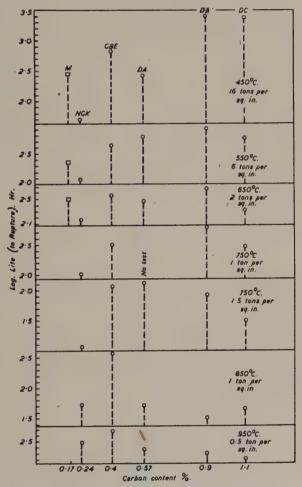


Fig. 3.—Creep Tests on Carbon Steels.

greatly inferior to DB, but the $1\cdot14\,\%$ carbon steel NKT is only slightly inferior to DC. The manganese content of steel NKT, $0\cdot33\,\%$, may be sufficient to give strength to the steel at this temperature. The steels were also tested at 450° C. for 960-1920 hr.

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NKE. DC. 0.86 1.10	16·0 16·0 16·0 16·0 16·0 16·0 12· 23.8 1680 U 5 72.	6.0 552 22* 44 65 76	202 97 166 87 88 83		: : : :	306 57 48	::::	0.25 1027 18*	::::	
NKE. 0.86		6.0 22* 65	2.0 97 88							
	16.0 166 12* 72		ଜା	1.0 284 16* 86	1.5 30 149 93	488 24* 29	1.0 44 89 65	0.25 2736 41 62	155 44 44	
. D.B. 0.90	-	6.0 33 78	2.0 166 94 82	1.0 423 36* 37	1 00 04 05 50 0 04 14 14 14 14 14 14 14 14 14 14 14 14 14	::::	1.0 35 49	::::	0.5 31 38 38	discontinued),
	16.0 2472 6.5*	6.0 792 24 42	2.0 458 48*	1.0 592 55 47	1.5 35 45	::::	32.0 27.27.27	::::	0.5 187 26 19	= unbroken (test discontinued),
NKS. 0.60	16.0 40 52 84	6.0 49 77	2.0 246 101 88	::::	::::	::::	::::	::::	::::	u = U
DA. 0.57	16.0 256 12* 84	60.0 255.0 78.0 78.0	289 289 66 89	::::	1.5 129 74* 49	::::	1.0 29 29 49	::::	233 27 27 22	
GBE. 0.40	16.0 663 31* 53	46.6.0 88.8 83.8	2.0 366 61 90	306 30* 30* 93	1.5 113 102 64	::::	372 94 92	::::	43.7 83 99	
NGK. 0.24	15.8 49 21.* 67	118 30* 82	1.95 144 69 93	0.95 100 111 92	1.5 11 131 92.5	756	1.0 25¢ 56	::::	292 33 29	length.
M. 0.17	242 242 594 594	6.1 53 79	1.95 262 32 65	0.95 87 120 78	::::	::::	::::	::::	::::	Broke outside gauge length.
Steel: Carbon Content, %:	Load. Tons per sq. in. Life. Hr. Elongation. % Reduction of area. %	Load. Tons per sq. in. Life. Hr. Blongation. % Reduction of area. %	Load. Tons per sq. in. Life. Hr. Elongation. % Reduction of area. %	Load. Tons per sq. in. Life. Hr. Blongation. % Reduction of area. %	Load. Tons per sq. in. Life. Hr. Blongation. % Reduction of area. %	Load. Tons per sq. in. Life. Hr. Elongation. % Reduction of area. %	Load. Tons per sq. in. Life. Hr. Blongation. % Reduction of area. %	Load. Tons per sq. in. Life. Hr. Elongation. % Reduction of area. %	Load, Tons per sq. in. Life. Hr. Blongation. % Reduction of area. %	* Broke o
Temp.,		550	650	750	750	850	850	950	950	

at a lower stress, namely, 8 tons per sq. in., so that the change in microstructure, if any, could be observed. The specimens extended by amounts ranging from 0.1 to 1.4%. These amounts were not sufficient to cause any acceleration of the changes occurring in the structures, *i.e.*, the changes in structure in these specimens are similar to any that might occur in unstressed specimens. Unstressed pieces for this comparison were annealed alongside many of the creep specimens throughout the tests set forth in Table IV.

One of the steels at present being discussed, namely, GBE, was considered in earlier work for the J/E Committee * on Steels for High-Temperature Service (see steel J in Table I. of the paper by Jenkins and others ⁽⁶⁾). This steel, which contains 0.40% of carbon, was found to be very similar in properties (as determined by creep tests lasting 20 days at 450° C. under a load of 8 tons per sq. in.) to the average of six steels of similar carbon content and of normal creep resistance. The total extension of GBE after 20 days was 0.23%, and the average of the six steels was 0.31% (range 0.14-0.44%). A test under the same conditions of stress and temperature has now been applied to steel NGK (0.24% of carbon). The resulting total deformation was 0.45%, whereas the average value for four steels containing 0.13-0.20% of carbon, also tested for the J/E Committee, was 0.24% of the gauge length (range 0.17-0.40% elongation). Thus steel NGK is relatively weaker than GBE. The results, which were discussed in the earlier paper, show that this steel is also weaker than steel M (0.17% of carbon). Data relating to these steels are plotted in Fig. 3.

The results of creep tests at 550° and at 650° C. under 6 and 2 tons per sq. in., respectively, show a less marked difference between the various materials than is apparent at 450° C. under a load of 16 tons per sq. in. The microscopical examination of these specimens, described in a later Section (see V. (c) viii), shows that graphitisation has had a noticeable influence on the results. The short life of steel NKS at 450° C. as compared with NKT is probably due to incipient graphitisation of NKS; it should, however, be contrasted with their similarity at 550° and 650° C., due to the graphitisation of both steels. The long life of steels DB, DC and NKT at 450° C. can be ascribed to the absence of ferrite and the freedom from graphitisation of the pearlite which constitutes the whole or greater

portion of the steel.

It is stated in the previous paper that the change in lattice at the A_3 point leads to an increase in the strength of iron and low-carbon steels under creep conditions. That paper also indicated that the materials of lower carbon content became relatively stronger than those of higher carbon content in both creep and short-time (tensile) tests, but the highest carbon content then considered was only 0.24%. In the present work the steels of high carbon content do not show an increase in strength in creep on changing

^{*} Of the British Electrical and Allied Industries Research Association.

from α - to γ -iron. Steel *GBE* tested under a load of 1 ton per sq. in. at both 750° and 850° C. is the only exception to this. This steel contains some free ferrite with the austenite at 750° C. but none at 850° C. In the previous Section on tensile tests it was stated that the steels of higher carbon content were also less affected than those of lower carbon content.

The creep specimens tested at 750° C. were in the majority of cases heated to 800° C. and cooled to the testing temperature before loading. It was found that by heating the specimens to 750° C.

the changes at the lower critical point were not complete.

It should be noted that steels NGK and the seven carbon steels containing over 0.40% of carbon are wholly in the austenitic condition at 850° C. In this condition steel GBE (0.4% of carbon) has superior creep strength in relation to the other steels. Steel NGK, which has a relatively short life at low temperatures, has a relatively long one at 950° C. It would appear that with rise of temperature in creep tests the steels of higher carbon content are not so strong as those of lower carbon content.

The higher proportion of manganese in steels DA, DB and DC appears to give these steels a generally greater creep strength than that of the steels NKS, NKE and NKT, which, as shown

later, graphitise rapidly.

(c) Comparison at 450° C., 650° C. and 950° C. of Steel DB (0.90% Carbon) with Materials of Low Carbon Content in Tensile and Creep Tests.

In view of the falling-off in strength of high-carbon steels at high temperatures, a comparison is made in Tables V. to VIII. of the properties at 450° , 650° and 950° C. of steel DB with those of certain materials of low carbon content. Steel DB, as shown in

Table V.—Creep Tests. Comparison at 450° C. of Low-Carbon Materials with Steel DB.

Steel.	Carbon Content.	Stress. Tons per sq. in.	Life. Hr.	Elonga- tion. %.	Reduction of Area.	
DB DB NGK NGK NGK R	0.90 0.90 0.24 0.24 0.24 0.07	16 8 15.8 10 8 10	2472 960 U 49 1176 960 U 308	6·5* 0·3 21* 10* 0·7 72	62 67 65 0.6 76	Brinell hardness number
R R R R R R R R R R R R R R R R R R R	0.07 0.07 0.07 0.07	8 8 10 5-6	960 U 1478 272	12.0 34 55	12.5 69 77	Treated for 384 br. at 650° O. before test. *Brinell hardness number 100.

^{*} Broke outside gauge length.

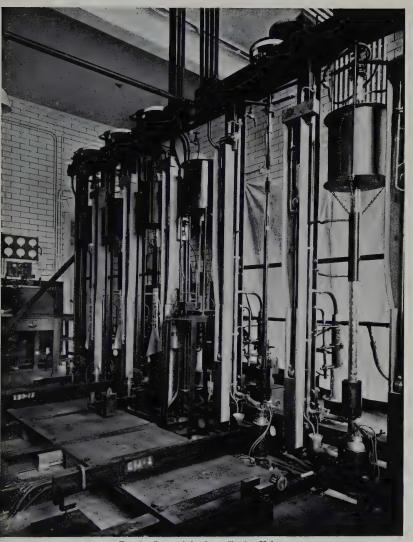
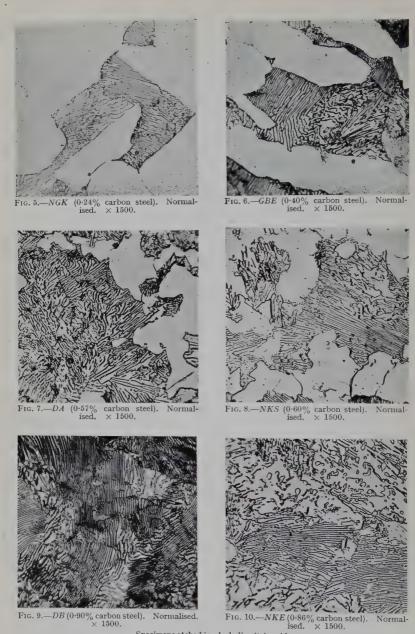


Fig. 4.—Some of the Creep Testing Units.

[Jenkins, Mellor and Jenkinson.

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Specimens etched in alcoholic nitric acid.

(Micrographs reduced to two-thirds linear in reproduction.)

[Jenkins, Mellor and Jenkinson.



Fig. 11.—DC (1·10% carbon steel). Normalised, \times 1500.



Fig. 12.—NKT (1·14% carbon steel). Normalised. \times 1500,



7_{1G.} 13.-DA (0.57% carbon). Short-time (tensile) test, 15° C. Section close to fracture, 46.6 tons per sq. in. \times 1500.



Fig. 14.—DB (0.90% carbon). Short-time (tensile) test, 15° C. Section at fracture, 64.4 tons per sq. in. \times 1500.



Fig. 15.—DC (1·10% carbon). Short-time (tensile) test, 15° C. Section close to fracture, 58·2 tons per sq. in. × 1500.



Fig. 16.—GBE (0.40% carbon). Short-time (tensile) test, 250°C. Section close to fracture, 41.0 tons per sq. in. \times 1500.

(Micrographs reduced to two-thirds linear in reproduction.)

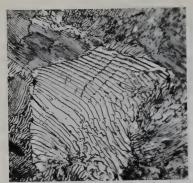


Fig. 17.—DB (0.90% carbon). Short-time (tensile) test, 250° C. Section close to fracture, 63.6 tons per sq. in. \times 1500.



Fig. 18.—DC (1·10% carbon). Short-time (tensile) test, 250° C. Section at fracture, 63·0 tons per sq. in. \times 500.



Fig. 19.—GBE (0.40% carbon). Short-time (tensile) test, 350° C. Section close to fracture, 40.8 tons per sq. in. × 500.



Fig. 20.—DA (0.57% carbon). Short-time (tensile) test, 350° C. Section close to fracture, 45.2 tons per sq. in. \times 500.



Fig. 21.—DB (0.90% carbon). Short-time (tensile) test, 350° C. Section close to fracture, 54.4 tons per sq. in. \times 500. Specimens etched in alcoholic nitric acid.

(Micrographs reduced to two-thirds linear in reproduction.)



Fig. 22.—GBE (0.40% carbon). Short-time (tensile) test, 450 °C. Section close to fracture, 31.2 tons per sq. in. \times 500.



FIG. 23.—GBE (0·40% carbon). Short-time (tensile) test, 450° C. Section 0·25 in, from fracture, 31·2 tons per sq. in. \times 1500.



Fig. 24.—DB (0.90% carbon). Short-time (tensile) test, 450° C. Surface after test, 39.1 tons per sq. in. \times 500.

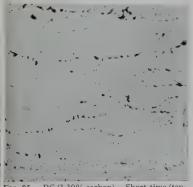


Fig. 25.—DC (1·10% carbon). Short-time (tensile) test, 450° C. Section close to fracture, 44·0 tons per sq. in. × 500.



Fig. 26.—DA (0.57% carbon). Short-time (tensile) test, 550° C. Section close to fracture, 23.4 tons per sq. in. \times 1500.

Specimens of Figs. 22, 23, 24 and 26 etched in alcoholic nitric acid; specimen of Fig. 25 unetched.

(Micrographs reduced to two-thirds linear in reproduction.)

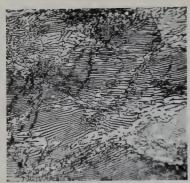


Fig. 27.—DB (0.90% carbon). Short-time (tensile) test, 550° C. Section 0.25 in. from fracture, 25.9 tons per sq. in. \times 1500.



Fig. 28.—DC (1·10% carbon). Short-time (tensile) test, 550° C. Surface after test 0·75 in. from fracture, 30·5 tons per sq. in. \times 1000.



Fig. 29.—GBE (0·40% carbon). Short-time (tensile) test, 650° C. Section close to fracture, 11·4 tons per sq. in. \times 1500.

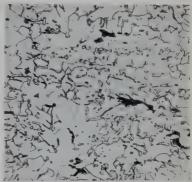


Fig. 30.—DA (0.57% carbon). Short-time (tensile) test, 750° C. Section close to fracture, 6.8 tons per sq. in. × 1500.



Fig. 31.—DA (0.57% carbon). Short-time (tensile) test, 750° C. Section 0.25 in. from fracture, 6.8 tons per sq. in. \times 1500.



Fig. 32.—DA (0.57% carbon). Short-time (tensile) test, 850° C. Surface after test 1.5 infrom fracture, 4.3 tons per sq. in. \times 500.

(Micrographs reduced to two-thirds linear in reproduction.)



l'i.g. 33.-DA (0·57% carbon). Short-time (tensile) test, 850° C. Iron-plated edge close to fracture, 4·3 tons per sq. in. \times 150.



Fig. 34.—GBE (0·10% carbon). Short-time (tensile) test, 950° C. Section at fracture, 2·95 tons per sq. in. \times 500.



Fig. 35.—DB (0.90% carbon). Creep test, 40 tons per sq. in., 400° C., 60 hr. Section close to fracture. Elongation 7%, broke outside gauge length; reduction of area 39%. \times 500.

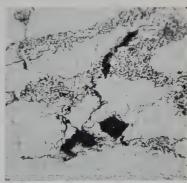


Fig. 36.—NGK (0.24% carbon). Creep test, 10 tons per sq. in., 450° C., 1176 hr. Section close to fracture. Elongation 10.4%, broke outside gauge length; reduction of area 65%. × 1500.

Specimens etched in alcoholic nitric acid. (Micrographs reduced to two-thirds linear in reproduction.)



Fig. 37.—GBE (0·40% carbon). Creep test, 16 tons per sq. in., 450° C., 663 hr. Section 0·12 in. from fracture. \times 1500.

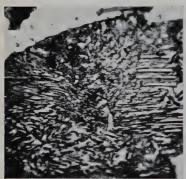


Fig. 38.—GBE (0·40% carbon). Creep test, 8 tons per sq. in., 440° C., 1848 hr. Surface after test. Elongation 0·10%, unbroken; reduction of area nil. × 1500.

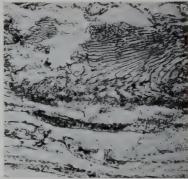
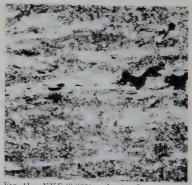


Fig. 39.—DA (0.57% carbon). Creep test, 16 tons per sq. in., 450° C., 256 hr. Section close to fracture. × 1500.



Fig. 40.-DC (1·10% carbon). Creep test, 16 tons per sq. in., 450° C., 2328 hr. Section 0·12 in. from fracture. \times 1500.



F16. 41.—NKE (0·86% carbon). Creep test, 10 tons per sq. in., 500° C., about 48 hr. Section close to fracture. Elongation 34%; reduction of area 82%. \times 150.

Specimens etched in alcoholic nitric acid.
(Micrographs reduced to two-thirds linear in reproduction.)



Fig. 42.—GBE (0.40% carbon). Creep test, 6 tons per sq. in., 550° C., 465 hr. Section close to fracture. \times 1500.

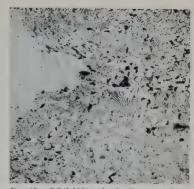


Fig. 43.—DC (1·10% carbon). Creep test, 6 tons per sq. in., 550° C., 552 hr. At iron-plated fracture. \times 500.



Fig. 44.—DC (1·10% carbon). Creep test, 6 tons per sq. in., 550° C., 700 hr. Section close to fracture. Elongation 46%; reduction of area 65%. \times 1500.

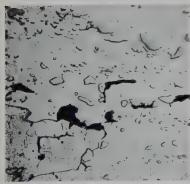


Fig. 45.—GBE (0.40% carbon). Creep test, 2 tons per sq. in., 650° C., 366 hr. Section at fracture. \times 1500.



Fig. 46.—GBE (0·40% carbon). Creep test, 2 tons per sq. in., 650° C., 366 hr. Section 0·25 in. from fracture. \times 600.

Specimens of Figs. 42, 44, 45 and 46 etched in alcoholic nitric acid; specimen of Fig. 43 etched in sodium picrate.

(Micrographs reduced to two-thirds linear in reproduction.)

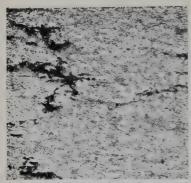


Fig. 47.—DA (0.57% carbon). Creep test, 2 tons per sq. in., 650° C., 289 hr. Section close to fracture. \times 150.

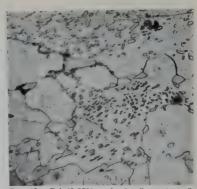


Fig. 48.—DA (0.57% carbon). Creep test, 2 tons per sq. in., 650° C., 289 hr. Section 0.25 in. from fracture. × 1500.

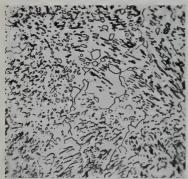


Fig. 49.—DB (0.90% carbon). Creep test, 2 tons persq. in., 650° C., 96 hr. Section at maximum reduction of area of unbroken test-piece. Elongation 2.6%; reduction of area 3%. × 1500.

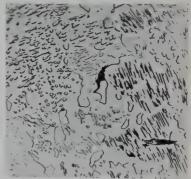


Fig. 50.—DB (0.90% carbon). Creep test, 2 tons per sq. in., 650° C., 216 hr. Section at most reduced portion of unbroken testpiece. Elongation 8%; reduction of area 9.7%. × 1500.

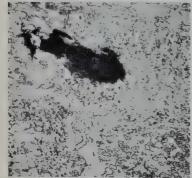


Fig. 51.—DB (0.90% carbon). Creep test, 2 tons per sq. in., 650° C., 458 hr. Section 0.12 in. from fracture. × 500.



Fig. 52.—NKE (0.86% carbon). Creep test, 1.5 tons per sq. in., 650° C., 912 hr. Section in screwed end of test-piece. Elongation 54%; reduction of area 58%. \times 500.

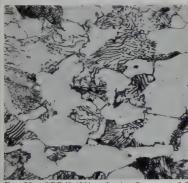
(Micrographs reduced to two-thirds linear in reproduction.)



Fig. 53.—NKE (0.86% carbon). Creep test, 1.5 tons per sq. in., 650° C., 912 hr. Section of test-piece renormalised after creep test, 1000° C., 15 min., A.C. See Fig. 52. × 1500.



Fig. 54.—NGK (0.24% carbon). Creep test, 1.5 tons per sq. in., 750° C., 11 hr. Section close to fracture. \times 1500.



Frc. 55.—GBE (0·40% carbon). Creep test, 1·5 tons per sq. in., 750° C., 49 hr. Section 0·25 in. from fracture. Elongation 152%; reduction of area 90%. × 1500.

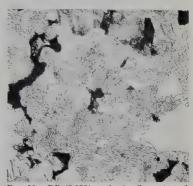


Fig. 56.—DB (0.90% carbon). Creep test, 1 ton per sq. in., 750° C., 592 hr. Section close to fracture. \times 500.



Fig. 57.—DB (0.90% carbon). Creep test, 1 ton per sq. in., 750° C., 592 hr. Section 0.25 in. from fracture. \times 1500.



Tr. 58.—DB (0.90% carbon). Unstressed material, 750° C., 592 hr. Section through sample. \times 1500.

(Micrographs reduced to two-thirds linear in reproduction.)



Fig. 59.—NKE (0.86% carbon). Creep test, 1 ton per sq. in., 750° C., 423 hr. Section close to fracture. \times 500.



Fig. 60.—NGK (0.24% carbon). Creep test, 1 ton per sq. in., 850° C., 51 hr. Section close to fracture. \times 1500.



Fig. 61.—DA (0.57% carbon). Creep test, 1 ton per sq. in., 850° C., 58 hr. Section close to fracture. Elongation 25%; reduction of area 22%. × 1500.

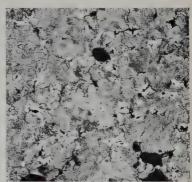


Fig. 62.—NKT (1·14% carbon). Creep test, 0·5 ton per sq. in., 850° C., 306 hr. Section close to fracture. \times 150.

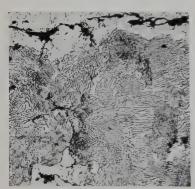


Fig. 63.—NKT (1·14% carbon). Creep test, 0·5 ton per sq. in., 850° C., 306 hr. Section at edge 0·25 in. from fracture. \times 500.



Fig. 64.—DA (0.57% carbon). Creep test, 0.5 ton per sq. in., 950° C., 233 hr. Section 0.5 in. from fracture. \times 50.

(Micrographs reduced to two-thirds linear in reproduction.)

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Table VI.—Creep Tests. Comparison at 650° C. of Low-Carbon Materials with Steel DB.

Steel.	Carbon Content. %.	Stress. Tons per sq. in.	Life. Hr.	Elongation.	Reduction of Area. %.
DB NGK	0.90 0.90 0.24 0.07 0.015	2 0·5 1·94 0·5 0·66	458 3024 U 144 2040 U 304	48 * 6·7 69 2·9 3 *	70 4·6 92 4·0 23

^{*} Broke outside gauge length.

Table VII.—Short-Time (Tensile) Tests. Comparison at 950° C. of Low-Carbon Materials with Steel DB.

	Chemical Analysis.					Tensile	Elonga-	Reduc-	
Material.	Carbon.	Silicon.	Man- ganese.	Copper.	Nickel.	Strength. Tons per sq. in.	tion.	tion of Area. %	
DB. NGK Carbonyl iron Armco iron A Armco iron H Swedish iron S Swedish iron L	0.90 0.24 0.015 0.016 0.022 0.017 0.034	0·12 0·05 <0·002 0·006 0·002 0·05 0·024	0.68 0.63 <0.005 0.030 0.035 0.005 Trace	0.013 0.09 <0.002 0.07 0.084 Nil 0.005	Nil Trace 0.011 0.03 0.048 Nil 0.004	2·33 3·35 2·51* 3·17 3·33	82 107 146 44 138	>99 99 >99 45 88 	

^{*} Some recent work on pure iron at this temperature shows a similar value. Further tensile and creep tests are in hand.

Table VIII.—Creep Tests. Comparison at 950° C. of Low-Carbon Materials with Steel DB.

The silicon, manganese, copper and nickel contents of the materials are given in Table VII.

Material.	Carbon Content. %.	Stress. Tons per sq. in.	Life. Hr.	Elongation.	Reduction of Area. %.
DB	0·90 0·24	0·5 0·5	187 292	26 33	19
0 1 1	0.015	0.35	19	11	30
$\begin{array}{c} \textbf{Armeo iron } A \\ \textbf{Armeo iron } H \end{array}$	$\begin{array}{c c} 0.016 \\ 0.022 \end{array}$	$0.44 \\ 0.44$	73 75	12 15	$\begin{bmatrix} 8 \\ 9 \end{bmatrix}$
Swedish iron S	0.017	0.5	197	17	19
Swedish iron L	0.034	0.5	212	22*	13

^{*} Broke outside gauge length.

the earlier part of this paper (Tables II. to IV.) is representative of steels DA, DB and DC, as shown by the results of short-time (tensile) tests and in creep tests. The proportion of silicon and

U = unbroken (test discontinued).

manganese in steel DB is also similar to that in steel DA and

steel DC.

The data on materials NGK, two Armco irons (A and H), carbonyl iron * and two Swedish (Lancashire) irons (S and L) and those on a further low-carbon steel R have been brought into the comparison. The full composition of most of these materials was given in the earlier paper, (1) while that of steel R is given below:

Steel R.

Carbon .		0.07%	Manganese		0.24%
Silicon .		0.009%	Nickel .		Trace
Sulphur .		0.034%	Chromium		Nil
Phosphorus		0.035%	Copper .		0.15%

This steel was made in a basic open-hearth furnace and was supplied

in the form of 1-in. dia. bars.

The results set forth in Table V. for DB, NGK and R show that under a stress of 8 tons per sq. in. at 450° C. there is a small difference between DB and NGK but a marked difference in elongation between these two steels and R, which has a poor creep resistance. If, however, DB and NGK are compared at a stress of 16 tons per sq. in. at the same temperature, NGK is decidedly inferior. The results of tests under a load of 10 tons per sq. in. on NGK and R confirm the poor creep resistance of R. At a similar stress a further specimen of R previously heat-treated at 650° C. for 384 hr. was tested. The object of this preliminary treatment was to saturate the ferrite solid solution with carbon at 650° C. and spheroidise any remaining carbide. There was no appreciable change in creep strength at 450° C. as compared with the normalised sample. A test at 450° C. of carbonyl iron, which is a material of low-carbon content (0.015%) containing very low proportions of silicon, manganese, nickel and copper (generally below 0.01% of any of these elements) shows that the creep resistance is of a lower order.

The tests at 650° C. are compared in Table VI. When a load of about 2 tons per sq. in. is applied to specimens of NGK and DB the difference in life is not so great as was noticed under a load of 16 tons per sq. in. at 450° C. A comparison of carbonyl iron, steels DB and R under a load of 0.66-0.50 ton per sq. in. at 650° C. shows that carbonyl iron is relatively very weak, but steel R (0.07% of carbon) appears to have attained a creep resistance at least equal to that of steel DB (0.90% of carbon). Thus the small proportions of some elements would at this temperature appear to have an important influence.

In the comparison of the results of short-time (tensile) tests at 950° C. given in Table VII., carbonyl iron is slightly stronger than the high-carbon steel DB. The three samples of low-carbon steel

^{*} Plate $\frac{6}{16}$ in. thick produced from a sintered powder of iron followed by a considerable amount of hot-working.

and iron mentioned in the Table are appreciably stronger. Thus carbon does not appear to impart strength at this temperature.

Reference to Table VIII. shows that in the creep tests at 950° C. steel NGK, which had an inherent weakness at 450° C., possesses superior resistance in creep under 0.5 ton per sq. in. The results of tests on two samples of Swedish iron and of two samples of Armco iron are also of the same magnitude as those of the high-carbon steel DB. A creep test on carbonyl iron at a lower stress demonstrates that this material is, as at lower temperatures, appreciably weaker than the high-carbon steel.

(d) Nature of the Fractures in Tensile and Creep Tests.

At low temperatures the short-time (tensile) test-pieces conform to the normal cup-and-cone type of fracture, but with increasing temperature the ductility rises, giving both greater general as well as local reductions of area, and hence smaller cup-and-cone fractures are formed. With increase of carbon content the fractures indicate less ductility, particularly at temperatures below 350° C. Above the $\rm A_1$ point the fractures of the steels, irrespective of the carbon content, are drawn down almost to a point.

The test-pieces broken in creep tests at temperatures from 450° C. up to the A_1 point have fractures in which the cup-and-cone type is not so well formed as in the tensile tests. Some tests in this range of temperature were also carried out at lower stresses than those shown in Table IV.; in these tests there appears to be less local

reduction at the fracture with the longer time of testing.

Above the A_1 point there is a marked change in habit. The creep fractures are not of the cup-and-cone type but are irregular, with little local reduction of area at the fractures. This absence of local ductility forms a marked contrast to the ductile behaviour at the fractures produced by short-time (tensile) tests and creep tests, the latter at 450° and 550° C. The absence of ductility is due to the gradual development of intercrystalline cracks in the material. This is very noticeable in a specimen of DC subjected to 0.25 ton per sq. in. at 950° C. for 2736 hr. Extensive cracking is found to penetrate right through the material.

V.—Microscopical Examination of Tensile and Creep Specimens.

(a) General Considerations.

The changes taking place in normalised mild steel were referred to in the previous paper. (1) Mild steel is known to consist of pearlite in a ferrite matrix. At atmospheric temperature and at temperatures below that at which appreciable self-annealing occurs, deformation begins by slip in the ferrite grains, but the interfering effect of numerous grain boundaries and of the grains of pearlite causes the movement to take place in a complex manner. The com-

plexity of this deformation is shown by the formation of very irregular strain markings in the ferrite, such as are described in the previous paper, and by the highly distorted character of the

pearlite.

At temperatures which allow considerable contemporaneous softening to proceed during the course of test, deformation is accompanied by a continuous process of recrystallisation and diffusion in the ferrite and the carbide coalesces into the spheroidised form. The rate at which this spheroidisation proceeds is very slow at 450° C. but is rapid at 650° C. Indications of the change can be seen even in short-time (tensile) tests at 550° C., but it should be noticed that in a test of this character the specimen has been hotter than 500° C. for probably more than one hour.

In the present work the changes observed in the microstructure have arisen from effects which are directly ascribable to the temperature, the duration of testing and the degree of deformation

given to the portion of the specimen examined.

The form of testing apparatus used does not have appreciable effect on the behaviour of the material, and thus for the purpose of the examination of the structural changes the short-time (tensile) test can be regarded as a creep test of very short duration. Unstressed pieces were in many cases inserted in the evacuated tube with the creep-test specimens. These helped to indicate the

effect of exposure to the temperature in the furnace.

After straining in the vacuum units, all specimens were cooled in the furnace by switching off the current. This cooling had no visible effect on the structure of those specimens which were below the A_1 point at the temperature of testing. In cases where the tests were conducted above the A_1 point the structures observed after cooling are not those existing at the testing temperatures. The structures obtained from these latter tests generally consist of well-separated ferrite and of pearlite having a characteristically lamellar form.

The micrographs illustrating this paper are arranged first as a series of short-time (tensile) test specimens and secondly as a series of creep specimens in the following order:

(1) Ascending temperatures.

(2) Increasing time of test at any given temperature, *i.e.*, decreasing load.

(3) Increasing carbon content.

Each micrograph has been arranged so that the transverse direction of the page represents the long axis of the test-piece.

In the descriptions attached to the micrographs certain terms are used which should be explained. "Section at fracture" implies that a portion of the iron-plated fracture is shown in the micrograph, whereas no part of the fracture is shown in an illustration marked "section close to fracture." In other cases of fractured

specimens the distance from the fracture is indicated. It is noteworthy that considerable differences in microstructure are found as the fracture is approached. It is important not only to take into account the degree of elongation found in the specimens but also the corresponding reduction of area at the point of fracture. (These results are given in Tables II., III. and IV.)

(b) Examination of the Polished Specimens after Deformation.

In the previous paper reference was made to the difference in behaviour of the surface layers from that of the underlying structure. A study of the surface layer revealed perhaps the initial mode of deformation. Fig. 24 illustrates the degree of distortion which has occurred in the pearlite grains of the eutectoid steel DB in a short-time (tensile) test at 450° C. At a higher temperature, 550° C., steel DC, which on account of its higher carbon content contains free cementite as well as pearlite, shows a less marked contrast between the appearance of the ferrite and the cementite lamellæ forming the pearlite (see Fig. 28) than is normally found. The free cementite is unaltered.

Fig. 32 illustrates the surface appearance of a 0.57% carbon steel after a short-time (tensile) test at 850° C. The presence of wide surface cracks is a noticeable feature. The structure below the surface of the parallel portion of the same test-piece (Fig. 33) shows that there are no cracks penetrating into the pearlite and ferrite of the steel underlying the iron-plated surface. This indicates that as soon as the stress, which is locally concentrated at the junction of the grain boundaries at the surface, has decreased, further widening of the surface cracks shown in Fig. 32 does not

take place.

Fig. 38 shows at a high magnification the appearance of pearlite in steel *GBE* which has been thrown into bold relief probably by slight relative movement of the ferrite on the cementite lamellæ. The neighbouring ferrite is not greatly altered. The total elonga-

tion on the specimen during the creep test was 0.1%.

(c) Results of Examinations of Changes in Structure.

(i) Ferrite Distortion.—Ferrite distortion was more apparent in the low-carbon materials described in the earlier paper $^{(1)}$ than in the steels set forth in Table I. The higher carbon content of these steels results in a lower proportion of free ferrite. (The four steels having a carbon content of 0.86% or above have no free ferrite and are excluded from this reference). The distortion is most readily seen in short-time (tensile) tests at low temperatures in which the time has not been sufficient for recrystallisation to occur. The strain markings in the deformed ferrite can be seen in the elongated ferrite grains in short-time (tensile) tests between 15° and 450° C. (see Figs. 13, 19 and 22). In a creep test at 450° C.

(see Fig. 37) the distortion is, however, less well marked, because with the longer time of test recrystallisation permits the easy

continued progress of deformation.

(ii) Ferrite Recrystallisation.—Although ferrite recrystallisation is well seen in the structure of both tensile- and creep-test specimens, it is more marked in the latter on account of the favouring action of the longer time. The effect was very prominent in the low-carbon steels described in the earlier paper, (1) which discussed the contemporaneous recrystallisation of strained material.

The effect in a short-time (tensile) test at 550° C. is shown in Fig. 26. The elongated grains of the steel DA, which possesses considerable ductility, are completely recrystallised. In tests on this steel and steel GBE at 650° and 750° C. (see Figs. 29, 30 and 31) the character of the ferrite grains becomes still more altered and a

new disposition of polyhedral crystals is observed.

In regard to creep tests, Fig. 39 illustrates partial and Fig. 36 almost complete recrystallisation of the ferrite in tests lasting 256 and 1176 hr. at 450° C. Furthermore, Figs. 39, 42 and 48 show the nature of the change in two steels tested for somewhat similar times at 450°, 550° and 650° C. A comparison of this type is somewhat difficult, as the degrees of deformation, which have an appreciable effect on the rate of recrystallisation, are not similar even in places equidistant from the fractures in the specimens.

- (iii) Crack Formation between Ferrite and Pearlite Grains.—This effect was observed only in steels GBE and DA in short-time (tensile) tests at low temperatures. Examples of these cracks are given in Figs. 20 and 22, which relate to specimens tested at 350° and 450° C. The proportion of ferrite to pearlite for this effect to occur is probably critical. It appears that the harder pearlite yields less than the softer ferrite. It should be observed that the boundaries between the grains of ferrite and pearlite do not appear to separate where these are parallel to the direction of pulling. The temperature is too low and the time too short for spheroidisation or graphitisation to be a prominent factor (see Section V. (c), vii and viii).
- (iv) Crack Formation in Cementite.—This form of cracking occurs in the grain boundaries of a high-carbon steel which has a carbon content in excess of the eutectoid composition, i.e., there is sufficient free carbon to form cementite in the grain boundaries. The cementite, which is a relatively brittle constituent, appears to rupture before the pearlite is noticeably deformed. The two steels, DC and NKT, which have a carbon content of about $1\cdot1\%$ and possess a pearlite + cementite structure, reveal this mode of crack formation and do not show the pearlite dislocation described in Section V. (c) v.

Crack formation in cementite is observed in specimens fractured in tensile tests at low temperatures and is a special type of intercrystalline weakness. A pearlitic steel in the absence of free

cementite does not suffer from this form of intercrystalline break-

down at low temperatures.

Examples of this are given in Figs. 15 and 18. In some cases the cementite appears to break in many places, and further extension of the grains causes these numerous discontinuities to enlarge into holes, as is shown in Figs. 18 and 25. The holes referred to are

the black dots in the grain boundaries.

(v) Pearlite Dislocation.—This form of movement, which probably occurs on a shear plane in the pearlite grains, is prevalent in short-time (tensile) tests in steels with carbon contents of up to 0.9%, and is mostly observed at temperatures below 250° C. Traces of its occurrence have, however, been observed in steels GBE and DB at a temperature as high as 550° C. In a low-carbon steel deformation has been shown to occur preferentially in the softer constituent ferrite, but in a high-carbon steel, with its lower proportion of ferrite, the deformation is not confined to the ferrite, but occurs also in the harder pearlite. It reveals itself not as a crack parallel to the lamellæ of the pearlite but as a slip or cleavage on planes approximately at right angles to the direction of these laminations and very often at 45° to the direction of pulling. angle probably corresponds to a shear plane in the ferrite of the pearlite most closely related to the plane of maximum shear stress in the test-piece. The occurrence was not described in the earlier paper in regard to the two low-carbon steels, but re-examination of some of the specimens shows that it was present to a small degree in the pearlite.

Figs. 13 and 14 illustrate the results of this form of transcrystalline movement occurring near the fractures of two specimens at 15° C. In the latter micrograph the course of the final fracture follows one of these cracks, which appears to have arisen on the site of a shear plane. Fig. 14 also shows that one of these dislocations

has been opened up to form a crack.

A comparison of Figs. 16 and 17 confirms that at 250° C. this form of dislocation is more sharply marked in short-time (tensile) tests on the higher-carbon steel than on the lower-carbon steel. Probably the presence of ferrite surrounding the pearlite as in Fig. 16 causes the deformation to be less localised, and a zone of deformation tends to be set up rather than a marked plane on which movement has occurred.

As the temperature of test rises the pearlite dislocation, although originally formed, is less noticeable at the fracture but is more in evidence at a distance from the fracture where the deformation was much less. It persists at higher temperatures more favourably in steels of higher carbon content. Figs. 23 and 27 show the presence of this form of movement at 450° and 550° C. at a distance of 0.25 infrom the fracture.

This form of movement by dislocation has also an influence on the appearance of the polished specimens after etching. Lines of marked pitting were set up along some of the dislocations such as are illustrated in Fig. 13. This effect is also apparent to a less

noticeable extent in Figs. 14 and 23.

The elongation of the grains as shown in Fig. 21 also brought about a marked crack development in the eutectoid steel DB at 350° C. In a test on the 0.4% carbon steel GBE at 450° C. (see Fig. 22) marked cracking was formed within the pearlite grains. This is in addition to the cracking between the ferrite and pearlite

grains already described.

This form of slip within the pearlite was also observed in two creep tests on steel DB at a somewhat lower temperature. In the test at 350° C. under a load of 40 tons per sq. in., rupture occurred in 3240 hr. after the specimen had extended 23% and the area of cross-section had been reduced by 37%. In the second test at 400° C., the specimen broke in a much shorter time. The form of slip is illustrated in Fig. 35 (particulars of testing are noted below the micrograph). The dislocations are shown in a crystal in the

lower left-hand corner of the micrograph.

(vi) Pearlite Distortion.—Pearlite distortion may be defined as a general deformation of the pearlite grains. It occurs at a somewhat higher temperature than pearlite dislocation and generally affects the whole of the pearlite grain, whereas dislocation affects only a portion. It produces a marked acceleration of the rate of spheroidisation as compared with that found in undeformed grains. Illustrations of the effect of distortion at 350° C. are reproduced in Figs. 19, 20 and 21, and at 450° and 550° C. in Figs. 22 and 26, respectively. In these short-time (tensile) tests both the ferrite and the pearlite grains are considerably elongated.

The appearance of Fig. 27 is of interest. It shows not only undeformed pearlite but pearlite altered by dislocation as well as grains of considerably distorted pearlite. The latter is commencing

to spheroidise.

(vii) Spheroidisation.—This effect is markedly apparent in creep tests at temperatures as low as 450-550° C.; it occurs in tensile tests at about 100° C. higher. Fig. 26 shows that the locally distorted pearlite commenced to spheroidise close to the fracture in a short-time (tensile) test at 550° C., and Fig. 27 that where the deformation was great, as in the zone of deformation around the dislocations, spheroidisation had also begun. The progress of spheroidisation is depicted in Figs. 26 and 27 and is considerably more advanced in Fig. 29, which relates to a short-time (tensile) test at 650° C. on steel GBE. Almost complete spheroidisation has occurred locally, but a little lamellar pearlite remains. The grain boundaries of the pearlite are beginning to be altered and the ferrite lamellæ in the pearlite are merging into the ferrite grains; as mentioned later, the time is too short for graphitisation of the spheroidised pearlite to begin. The black zones are holes produced in the region of the fracture.

In creep tests the effect of the duration of exposure to the temperature of testing becomes a prominent feature. The equation connecting spheroidisation with time at any particular temperature as proposed by R. W. Bailey was referred to in the earlier paper. (1)

In a series of steels tested at 8 tons per sq. in. at 450° C. for 960 hr., all the steels were unbroken but had extended various amounts. Steel NKE (1·4% extension) underwent some degree of spheroidisation, but steels NGK, NKS and NKT were only changing slowly after 0·7%, 0·9% and 0·4% extension, respectively. Steels GBE, DA, DB and DC showed no change in structure, but the extensions of the specimens were 0·1%, 0·2%, 0·3% and 0·4%, respectively.

Creep tests for a prolonged time at 450° C. were made under a load of 8 tons per sq. in. on steels GBE and DA. In neither case was the specimen broken, but steel GBE lengthened 1.12% after 5712 hr. (1.30% reduction of area) and steel DA 0.43% after 3912 hr. (0.50% reduction of area). The examination of specimen GBE under the microscope shows that the lamellæ of cementite have become thicker at their ends. There is also some loss of definition in the boundary between the pearlitic grain and the neighbouring The initial movement of the cementite thus occurring is indicative of the beginning of spheroidisation. The formation of deformed areas within the pearlite grains has commenced. These deformed areas would later resemble the type shown in the tensile test on DB, reproduced in Fig. 27 (see Section V. (c) vi). Steel DA, on the other hand, shows very little change. The deduction is made that the difference in the time of testing of the two specimens is not sufficient to account for the difference in microstructural change, and that about 1% elongation is necessary to produce the changes that have occurred in steel GBE. Steel DA has not been extended to this degree, and therefore little change has occurred.

When an increased rate of deformation was given to a specimen of NGK by increasing the load from 8 to 10 tons per sq. in. at 450° C., rupture took place in 1176 hr., accompanied by rapid spheroidisation,

as shown in Fig. 36.

In creep tests on all the steels under a load of 16 tons per sq. in. at 450° C., the deformation which proceeded to rupture caused partial spheroidisation near to the fractures, except in the case of NGK. Examples of the degree of coalescence of the lamellæ are given in Figs. 37 and 39, which relate to steels GBE and DA after 663 and 256 hr., respectively. NKS, which is a rapidly graphitising steel, showed this coalescence after rupture in 40 hr. This steel contains the highest ratio of silicon to manganese. NGK, however, ruptured in 49 hr., but coalescence did not occur during the short period of the test, possibly on account of the high proportion of manganese. The earlier paper (1) describes a series of creep tests on this steel at stresses between 10 and 18 tons per sq. in., and the plotted data given in Fig. 5 of that paper show that the life of NGK at a stress of 15.8 tons per sq. in. at 450° C. (namely,

49 hr.) is not exceptional. The paper also states that at a stress of 13·25 tons per sq. in. at 450° C., spheroidisation occurred in the

neighbourhood of the fracture after 310 hr.

The creep-test specimens of steel R tested at 450° C. under a load of 10 tons per sq. in. (see Table V. and Section IV. (d)) were examined. After 308 hr. the pearlite grains in the normalised material have retained their grain boundaries, but have begun to lose their lamellar character where deformation has been greatest, while the originally spheroidised material shows after 272 hr. considerable distortion of the ferrite grains and the presence of cementite globules in the ferrite boundaries. The latter were present in those positions owing to the action of the spheroidisation treatment given before test.

The rate of spheroidisation at higher temperatures of two steels, NKE and GBE, can be compared (see Figs. 41 and 42). A comparative examination carried out at the higher magnification used for Fig. 42 showed that both steels had become equally spheroidised. The test on steel NKE lasted only 48 hr. at 500° C., while that on GBE occupied 465 hr. at 550° C. (The black areas in Fig. 41 indicate the presence of graphite in NKE; there is less of this constituent in steel GBE, as is shown in Fig. 42. The formation of graphite is described in Section V. (c) viii). The rapidity of the structural change in steel NKE is probably ascribable

to the low ratio of manganese to silicon.

The greater rate of spheroidisation on increase of temperature can be seen in the short-time (tensile) test of steel GBE at 650° C., cf. Figs. 29 and 22. After a creep test at 2 tons per sq. in. lasting 144 hr. at this temperature, steel NGK was well spheroidised (see Fig. 45 of the earlier paper ⁽¹⁾). In a specimen of steel GBE tested for 366 hr. at 650° C. the pearlite shows little trace of its original lamellar character, and some of the particles of spheroidised carbide have appreciably grown in size (see Figs. 45 and 46). Figs. 47 and 48 illustrate the effect of similar testing conditions on steel DA. Spheroidisation is complete at the fracture in both creep specimens of GBE and DA at 650° C., but away from the fracture there is still an indication of the shape of the former pearlite grains.

The present work shows that at similar distances from the fracture the progress of spheroidisation is not always uniform across the specimen. There appear to be certain conditions of temperature and stress which bring this about. It is significant in this connection that many of the specimens of carbon steel in the range 450–550° C. (see Table IV.) break after deformation in creep with a low elongation but with a relatively high reduction of area. Examination of these specimens under the microscope reveals that these effects are related to spheroidisation set up by the various localised movements within the ferrite and pearlite. The resultant rapid decrease in strength on locally spheroidised areas causes still further local deformation until finally rupture sets in. An example of this

in steel DA (see Fig. 39) shows a locally highly distorted structure and an appreciably spheroidised pearlite. On the other hand, even near the fracture pearlite is found to occur which has been only slightly deformed. In this same test-piece, however, no distortion occurred at a distance of $\frac{1}{4}$ in. from the fracture. This form of highly localised deformation may account for the sudden failure of certain specimens. The steel in such tests offers, during the greater part of the test, a fair or good resistance to creep over a long period. Then the creep rate rises unusually rapidly, and the rapid deformation thus ensuing terminates the life of the specimen. The microscopical examination shows that the portion of the specimen near the fracture is locally highly altered, whereas the greater portion of the test-piece remains relatively unaltered when this effect occurs. Duplicate tests do not give good agreement in the life to failure.

(viii) Formation of Graphite from Cementite below the A_1 Point.— This occurs principally during creep tests, as the time of testing in short-time (tensile) tests is insufficient for graphitisation to take place. Spheroidisation of the carbide precedes this effect, which

occurs at a slower rate.

It is difficult to distinguish between the initial stages of graphite formation and crack formation, but when these two effects are well developed the difference is readily seen (Figs. 41 and 22,

respectively).

In the first place consideration is given to the formation of graphite in unstressed material. Heat treatment at 650° C. for periods of 120 and 360 hr. was undertaken to ascertain the rate of graphitisation of the various steels used in this work. After 120 hr. at 650° C. the carbide in steels NKS, NKE and NKT was partially graphitised, but steels NGK, GBE, DA, DB and DC were not appreciably altered. After 360 hr. steels NKS, NKE and NKT were almost completely graphitised; DB was a little graphitised and DC considerably. Steels NGK, GBE and DA were not changed. Microchemical analyses for the graphite content of samples of DC after 360 hr. at 650° C. are referred to in Section V. (c) x.

On considering the behaviour of the steels, the degree of deformation markedly accelerates the change, particularly at low temperatures, 450–550° C. An increase of temperature markedly increases the rate of graphitisation, and thus in short-time (tensile) tests at 750° C. traces of graphite are formed. Fig. 30 shows that steel *DA* graphitises near the fracture, but where the deformation is less, as in Fig. 31 at 0.25 in. from the fracture, no graphite is found.

The microscopical examination indicates that at 750° C. in short-time (tensile) tests the steels remain in the α condition. Confirmation of this is given by the plotted results of the tensile-temperature curves (see Fig. 1) which show that the properties undergo a marked change in the region above 750° C. but below 850° C.

In creep tests at 750° C. the pearlite and some of the ferrite in the steel tend to transform to the austenite solid solution. An example of this is given in Fig. 55; which shows that the structure of steel *GBE*, which was not heated in excess of 750° C., consisted of austenite and ferrite at the testing temperature. The effect of graphitisation in creep tests at 750° C. is referred to in Section

V. (c) ix.

A series of creep tests on the eutectoid steel DB at 650° C. was made under a load of 2 tons per sq. in. for periods of 96, 144, 216, 240 hr. and until fracture, which occurred after 458 hr. After 96 hr. there is some spheroidisation (see Fig. 49), and although the cross-section of the specimen was reduced in area by 3.4%, no graphite is found. After 144 hr. (6.4% maximum reduction of area) the cementite particles have noticeably increased in size. but it is not until the specimen has been loaded for 216 hr. (9.7%) maximum reduction of area) that graphite begins to appear at the point of maximum reduction (see Fig. 50). An undeformed specimen held alongside the stressed one in the evacuated tube contains no graphite after 216 hr., but after 240 hr. the formation is seen to have begun. In the tests described the usual more or less uniform drawing-out of the specimens does not take place. It was observed that the specimens cease to extend at one neck and begin to deform at another unnecked portion. For example, in the 240-hr. specimen at 650° C. there is a variation in reduction of cross-sectional area of between 7% and 17%.

At lower temperatures graphitisation proceeds at a slower rate. Fig. 37 shows that in a specimen of GBE no graphite was formed after 663 hr. at 450° C. under a load of 16 tons per sq. in. Several of the high-carbon steels were examined under similar testing conditions, and rupture occurred in steels DA in 256 hr, in DB in 2472 hr., in DC in 2328 hr. and in NKE in 166 hr. Although all the specimens show slight spheroidisation in the region of the frac-

tures, no graphite was found in any instance.

A creep test at 450° C. under a stress of 8 tons per sq. in. was carried out to rupture in 4340 hr. on a 0.4% carbon steel which is known to possess an abnormally high rate of creep (steel B in Table I. of the paper by Jenkins and others. This steel was prepared in a basic-lined Héroult furnace. It was dead-melted and killed by an addition of aluminium to the ladle. It was supplied in the form of plates 1 in. in thickness and the test-pieces were normalised before use). The examination of this specimen, which broke with an elongation of 41% and a reduction of area of 68%, shows that small particles of graphite were formed at or close to the fracture. The graphitisation has proceeded sufficiently far to produce a network, and this formation has hastened final fracture. This specimen underwent spheroidisation at a correspondingly greater rate than that observed in relation to steel GBE in a test lasting 5712 hr. (see Section V. (c) vii) and even shows cementite near to the fracture

in a well-dispersed state. No graphite was present in steel GBE, but it had lengthened by only $1\cdot12\%$. An additional specimen of NGK which was tested at 8 tons per sq. in. for 1704 hr. contained no graphite, probably on account of the small degree of deformation, but this specimen appeared to creep at a slower rate than the specimen referred to in Section V. (c) vii (elongation $0\cdot8\%$, reduction of area $0\cdot5\%$). Graphite was, however, found in a specimen tested at the same temperature, 450° C., under a load of 10 tons per sq. in., when fracture occurred in 1176 hr.

Confirmation of graphite formation at 450° C. was obtained in creep tests on a further steel * referred to as EVN1-2 containing 0.13% of carbon. The test-piece, which was loaded at 7 tons per sq. in., broke in 23,088 hr. with an elongation of 34%. Considerable elongation of the ferrite and pearlite grains occurred, accompanied by recrystallisation of the ferrite and complete spheroidisation of the pearlite. Graphite was also formed noticeably near to the fracture; its quantity decreases as the distance from the fracture becomes greater. At 1 in. from the fracture none is present. The graphite content of the material is given in Section V. $(c) \times (4)$.

A prolonged service test under conditions which would not lead to appreciable deformation was considered by the J/E Committee. No graphite was found (i.e., less than 0.005% by analysis) in a steam conveying pipe about 7 in. in internal diameter. This pipe was subjected to a temperature above 418° C. for 54,000 hr. and the greater part of the service was between 430° and 440° C., the maximum recorded being 447° C. The stress set up by the steam pressure amounted to only 2.2 tons per sq. in. The composition of the steel was: Carbon, 0.18%; silicon, 0.20%; sulphur, 0.021%; phosphorus, 0.017%; manganese, 0.58%; nickel, 0.03%; and chromium, nil.

Graphite was produced in a creep test of steel NKE at 500° C. in as short a period of time as 48 hr. (see Fig. 41). The more slowly graphitising steel DC shows graphite after 552 hr. (see Fig. 43 †) at 550° C. The difference in the rates of spheroidisation noticed in Section V. (c) vii in regard to steels NKE and GBE (see Figs. 41 and 42) was ascribed to the low manganese-silicon ratio. This increased rate of spheroidisation is of interest, as it is well known that a low ratio in high-carbon steels increases the rate of graphitisation.

Steel \overline{DB} in creep tests at 550° C. (6 tons per sq. in.) and at 650° C. (2 tons per sq. in.) lasted 792 hr. and 458 hr., whereas steel

^{*} This steel, also referred to in Table I. of the paper by Jenkins and others $^{(6)}$ as steel A, was prepared in the same manner as steel B referred to above.

[†] This specimen was etched in a boiling solution of sodium picrate and shows the regular distribution of the carbide particles and some graphite. The graphite as seen in an unetched specimen or one etched in a nitric acid solution is regularly distributed. The secondary ferrite as seen in a specimen etched in the hot sodium picrate solution appears to be aggregating into faint bands.

DC in similar tests lasted 552 and 202 hr., respectively. At 450° C. (16 tons per sq. in.) the steels were equally strong. The lower strength of the higher-carbon steel at higher temperatures might

be due to the graphitisation of the boundary cementite.

As previously stated, deformation appears to accelerate both the spheroidisation and the growth of the carbide particles. The general effect is seen in Figs. 42 and 48 and in Fig. 42 of the previous paper. The micrographs suggest that it is the larger particles of carbide which graphitise in the first instance, and it is thought that these particles perhaps graphitise when they attain a critical size. In the series of tests on steel DB at 650° C., which has been previously described, some measurements of the carbide particle size necessary before graphite is formed were made. The approximate diameter ascertained from 216-240-hr. tests is 0.00012-0.00016 in.

As the creep tests proceed the graphite areas grow, until the carbon of the neighbouring cementite has been converted. is an example of this occurring in steel DB tested at 650° C. for 458 hr. As graphitisation of the cementite proceeds the free ferrite around the graphite increases in quantity (see Fig. 51). The cementite of steel NKE tested at 650° C. for 912 hr. has been wholly transformed and the steel consists only of ferrite and graphite, as in Fig. 52. This micrograph relates to the centre of the screwed end of the test-piece where deformation was almost absent. The microstructure of a piece from the screwed end which had been air-cooled from 1000° C. after a heat treatment lasting 15 min. (see Fig. 53) shows that most of the graphite has gone into solution in the austenite at the high temperature and the carbon-bearing austenite has broken down into pearlite on cooling. Further samples of the material referred to in Figs. 51 and 52 were heat-treated at 850° C. for 15 min. and then air-cooled. At this temperature the graphite was mostly dissolved in the austenite, but a small proportion of graphite remained undissolved. Wells (7) indicates that the proportion of carbon in iron-carbon alloys of similar carbon content to NKE and DB is not sufficient to saturate the austenite at either 1000° or 850° C.; probably the annealing time of 15 min. is not sufficient for complete solution (see also Section V. (c) ix).

A comparison of the strength of steels DB and R in creep at 650° C. has already been given in Section IV. (d). The microstructure of these two materials after creep tests at 650° C. under a load of 0.5 ton per sq. in. are of interest. Steel DB tested for 3024 hr. has undergone considerable graphitisation, whereas R, with a carbon content of only 0.07%, shows no graphite after 2040 hr. In the case of steel R the pearlite grains have disappeared and the carbon is mostly present in solid solution in the ferrite, but a small quantity is found as carbide globules in the grain boundaries. The unstressed specimen of steel R after the same time at 650° C. is in a very similar condition, whereas the unstressed specimen of DB shows less graphitisation than its corresponding stressed specimen.

A specimen of steel GBE, held alongside the DB test-piece, is commencing to graphitise. After many of the tests at 550° and 650° C. the surface of the specimens was covered with a coating of graphite,

which had presumably diffused from the interior.

(ix) Formation of Graphite above the A_1 Point.—In the irongraphite diagram suggested by Wells ⁽⁷⁾ steels of similar carbon content to steels NGK, GBE, DA, NKS, NKE and DB should consist of austenite at 850° and 950° C., and those similar to DC and NKT should contain graphite in addition to austenite at 850° C. but not at 950° C. The present work suggests that in material deformed during exposure to the testing temperature the austenite is saturated at a lower carbon content * than is indicated by Wells, who studied high-purity alloys which were not deformed during his experiments.

Unstressed specimens of all the steels considered in this paper were annealed at temperatures of 800° , 850° and 900° C. for periods of 240 hr. in a high vacuum. The microstructures of steels NKE and NKT show that a little graphite was present with the austenite at all these temperatures, but none was found in steels NGK, GBE, NKS, DA, DB and DC. Chemical analysis revealed graphite in steels NKE and NKT after the 240-hr. periods at these temperatures (see also Section V. (c) x). The higher proportions of manganese in steel DB and DC as compared with steels NKE and NKT have

apparently slowed down the rate of graphitisation.

An examination of several unstressed specimens annealed alongside creep specimens is of interest. The microstructure of a specimen of steel GBE heated for 488 hr. at 850° C. contains no graphite, whereas that of DC heated for a similar time has a small proportion of graphite. At 950° C. steel NKT, after exposure for a long time, namely, 1027 hr., and steel DC after 2736 hr., have a small quantity of graphite. In these specimens of NKT and DC the carbon content appears, as seen under the microscope, to be about 0.90%. It is likely that some of the carbon dissolved in the austenite has formed graphite and has subsequently been removed by diffusion to the surface of the specimen.

In short-time (tensile) tests at 850° and 950° C. there is not sufficient time for graphite to form, and in consequence high values for the percentage elongations and reductions of area are obtained (see Table III.). (In Section V. (c) viii it was noted that a short-time (tensile) test at 750° C. resulted in graphitisation, but the steel

was, of course, in the a condition).

Specimens tested in creep at 850° and 950° C. were less ductile than those subjected to short-time (tensile) tests at the same temperature. Steel *GBE* is an exception, showing high ductility both in short-time (tensile) tests and in creep tests (see Tables III. and IV.).

^{*} See paragraph on next page referring to Fig. 62.

Wells $^{(7)}$ has also shown that in iron-carbon alloys of high purity graphite forms directly from carbon-bearing austenite as well as from cementite. The present work demonstrates its formation similarly in steels. Figs. 59 and 63, of steels NKE and NKT, respectively, show large areas of graphite formed during test from the carbon-bearing austenitic solid solution. Increase in the time of creep tests allows the graphitic areas to grow in size. In the case of high-carbon steels DC and NKT, where free grain-boundary cementite occurs, graphite forms from this cementite at a more rapid rate than from austenite.

The present examination indicates that the formation of graphite is very much slower from the carbon dissolved in the austenite solid solution than from the cementite such as exists at 650° C.

(here associated with the ferritic state).

Steels NKS, NKE and NKT which graphitise more rapidly below A_1 than steels GBE, DA, DB and DC (see Section V. (c) viii), have the same tendency above A_1 . For example, in creep tests at 750° C. under a load of 1 ton per sq. in., steel NKE, with a life of 423 hr., was compared with steel DB after 592 hr. The separation of free ferrite surrounding the graphite in steel NKE shows that the decomposition has progressed further than in steel DB (see Figs. 59 and 56).

Graphite was not definitely traced in creep tests in steel M at 750° C. (no test was made above this temperature, see previous paper ⁽¹⁾) nor in NGK (see Fig. 54), GBE and DA above the A_1 transformation. No test on steel NKS was made in this temperature range. Chemical analysis of two specimens of DA tested at 850° C. under a load of 1 ton per sq. in. did not indicate that

graphite was present.

Fig. 62 reveals the presence of coarse graphite in a specimen of NKT tested at 850° C. Chemical analysis (see Section V. (c) x) shows that 0.35% of graphite is present in this steel. The graphitic areas are enclosed in a well-marked ferritic grain, the presence of which confirms the fact that the combined carbon content has fallen below 0.9%. Fig. 63 illustrates the structure near the surface of the test-piece about 0.25 in. away from the fracture. Fine graphite is present in addition to the coarse graphite noted in Fig. 62. The surface of the test-piece—the dark band at the top of the micrograph—is coated with a layer of graphite which diffused to the surface from within the specimen. The electrodeposited coating of iron preserved the graphite during polishing. Underlying the graphite a thin layer of free ferrite occurs. This is caused by graphitisation of the austenite, as described in the next paragraph.

In a consideration of the cause of the presence of ferrite close to the graphite, it should be remembered that the generally accepted stable and metastable constitutional diagrams of the iron-carbon alloys show that at a temperature slightly above that of the eutectoid in each of these diagrams the solubility limit of graphite in austenite is lower than that of iron carbide in the same constituent. Thus the austenite has, on account of graphitisation, a carbon content lower than that of the eutectoid composition in the iron/iron-carbide system. On subsequent cooling the austenite present will transform to pearlite and ferrite. This ferrite is the first constituent to separate and will therefore tend to form on any nucleus present. Graphite particles appear to act as favourable nuclei.

The presence of graphitic areas in certain high-carbon steels leads to weakness in the material, and this facilitates the development of cracks. In Section V. (c) xii the intercrystalline character

of these cracks in relation to the y grains is described.

Graphite forms more readily at the point of maximum deformation in the test piece. A comparison of Figs. 56, 57 and 58 of steel DB tested at 750° C. shows the marked effect of deformation and

that the greatest change is seen near the fracture.

(x) Additional Information on Graphite Formation.—Microchemical analysis of residues is capable of showing the presence of graphite to a value as low as 0.005%. Owing to the relatively rapid aggregation of the particles, microscopical examination is also capable of revealing the presence of this quantity of graphite. Difficulties, however, arise in the polishing of specimens, for not only may graphite be dislodged, in which case specimens will appear to have a lower amount than their true content, but holes of certain shape may include polishing material which may be mistaken for graphite, thus giving a fictitiously high value. Some of the special polishing methods designed to obviate the first-named difficulty may increase the latter.

Several analyses have been made, the results of which are recorded below:

(1) Unstressed samples of steel DC after exposure to 650° C. for 360 hr. showed that from 0.03% to 0.12% of carbon, present originally as carbide, had been converted into graphite. The graphite had diffused and segregated appreciably after its formation.

(2) A creep test on steel NKE, which was wholly graphitised

after 912 hr. at 650° C. (Fig. 52) was repeated. The further specimen lasted 700 hr., and in a portion of the test-piece 0.85% of graphite

was found.

(3) Steel NGK, as previously discussed in Section V. (c) viii, contained 0.08% of graphite close to the fracture and 0.03% at 1 in. from the fracture. The specimen had ruptured after 1176

hr. at 450° C. under a load of 10 tons per sq. in.

(4) An examination of a further carbon steel (EVN1-2, 0.13% of carbon, referred to in Section V. (c) viii) showed that only 0.03% had become converted into graphite after 23,088 hr. at 7 tons per sq. in. at 450° C. The specimen was cut as close to the fracture as possible.

(5) Unstressed samples of NKE and NKT were heated at

1942—i

 800° , 850° and 900° C. for 240 hr. in a high vacuum. Chemical analysis revealed that 0.010-0.015% of graphite was present in

NKE and 0.005-0.015% in NKT at these temperatures.

(6) Two creep-test specimens of steel DA, with 0.57% of carbon, tested at 850° C. under a load of 1 ton per sq. in. contained no graphite (i.e., a content below 0.005%). This is in conformity with the appreciably higher solubility of graphite in iron in the austenitic condition than of graphite in iron in the ferritic state (cf. paragraphs (2), (3) and (4) above).

(7) A creep specimen of NKE tested for 52 hr. at 850° C. under

a load of 1 ton per sq. in. contained 0.01% of graphite.

- (8) A creep test-piece of steel NKT tested for 306 hr. at 850° C. under a load of 0.5 ton per sq. in. showed that 0.35% of the carbon content had been converted into graphite. From this fact and from the data in paragraph (7) above it is concluded that the limit of solubility of graphite in austenite is about 0.8% in a steel at 850° C.
- (9) In normalised samples of GBE, DA, NKE and NKT the graphite, if present, did not amount to 0.005%.
- (xi) Influence of Graphite on Crack Formation.—The decomposition of the carbide into graphite, as described in the previous three sub-sections viii to x, materially weakens the steels, thus decreasing the life under test. Furthermore, the graphitic areas formed in creep tests act as discontinuities and cracks develop between them (see Figs. 36, 56, 59 and 62). These cracks favour a course which is intercrystalline to the ferrite grains in tests below the A_1 point (Figs. 36), and to the austenite grains in tests above the A_1 point (Figs. 56, 59 and 62).

A comparison of Figs. 22 and 36 shows the marked difference between the general form of cracking under deformation in a short-time (tensile) test and that influenced by graphite formation.

Cracking in the high-carbon steel *DC* progresses by a mechanism somewhat different from that in the steels of lower carbon content. In this steel (see Figs. 40 and 44) cementite occurs in the boundaries and graphite first forms from the decomposition of this carbide. The intergranular weakness due to the presence of graphite is apparent. The lamellar pearlite within the grains is still in many cases unaltered even when the cementite referred to above is graphitised.

Deformation speeds up graphitisation and hence (cf. Figs. 47 and 48) cracks are formed first in the more highly deformed areas.

(xii) Mode of Rupture above the A_1 Point.—In short-time (tensile) tests at 850° and 950° C. there is insufficient time during the test for structural changes such as graphite formation to occur. High values for elongations and reductions of area are given by all steels. No cracks apart from shallow surface cracks are present, but holes, often drawn out into longitudinal fissures (the appearance of which

is quite different from that of graphite), are found near the fracture, as in Fig. 34.

Rupture, in creep tests above the A_1 point, is related to the slow formation of some intercrystalline cracks and of graphite. The rate at which graphitisation is occurring is, however, not rapid. Steel NKT after tests at 750° and 850° C. shows that cracking is set up by the formation of graphitic areas in the material during test. An example of this is given in Figs. 62 and 63. Steels DB and NKE show this at 750° C. similarly, and steel DC also at 750° and 850° C. As mentioned previously, steels DC and NKT formed

only a small quantity of graphite at 950° C.

In the previous paper (1) the following reference to steel NGK was made: "Fig. 49 relates to a specimen tested at 950° C. The specimen shows a coarsely separated form of pearlite, but there is no clear evidence that at the testing temperature the original large austenitic grains, from which the constituents have been subsequently derived on cooling, possess any general intercrystalline weakness." Mention was made at the same time that Armco ingot iron had a marked tendency to develop intercrystalline cracking at high temperatures. In the present work much further testing has been done on steel NGK at 750°, 850° and 950° C., and the results of the examination of these specimens and a re-examination of tests reported in the previous paper (1) indicate that there is some tendency for intercrystalline cracks to be present in this material (see Figs. 54 and 60). In the former an intercrystalline crack is developing between the ferrite and the austenite at the temperature of testing, and the lengthening of the specimen has drawn the crack out into a hole. Graphite has not been formed.

The deformation of steel DA at both 850° and 950° C. (see Figs. 61 and 64) occurs in an intercrystalline manner. This development of cracking is similar to that in steel NGK and is not accompanied by the formation of graphite. The cracks at 950° C. formed a series of bands across the specimen. Steel GBE, however, behaves in creep tests in the same way as in the short-time (tensile) tests, and even the longest time of testing, 437 hr., did not induce intercrystalline cracking. There was evidence that in steel GBE recrystallisation occurred in the austenitic grains at the temperature of testing; this is shown by the difference in the grain size of the pearlite (which forms from the austenite on cooling) in various specimens tested at 850° and 950° C. Near the fracture, where recrystallisation of the austenite had occurred under deformation, the pearlite is fine, but 0.25 in. away coarse pearlite is found.

VI.—Conclusions.

The well-known action of carbon in improving the strength of steel at atmospheric temperature is considerably modified at elevated temperatures. In short-time (tensile) tests carbon pro-

duces a strengthening action, which diminishes in high-carbon steels as the temperature rises from 250° to 650° C. In creep tests a eutectoid steel has appreciable strength at 350° C., but the resistance to deformation drops markedly between 350° and 400° C. In the range 550–650° C. long-time creep tests show no pronounced strengthening action by the presence of carbon up to $1\cdot2\%$, but there is a very appreciable variation in the strength of steels due to the presence of other elements such as silicon and manganese. At 950° C. both short-time (tensile) tests and creep tests show that low-carbon steels have a strength not less than that of high-carbon steels. Carbonyl iron is even slightly stronger than a 0·9% carbon steel in tensile tests at 950° C. but is weaker in creep tests.

The effect of the polymorphic transformation at the critical range is of interest. Although there is a marked increase in strength in a low-carbon steel on passing through the A_1 - A_3 range, there is

no sudden increase in the strength of a high-carbon steel.

Microscopical examination reveals that many changes occur in the material below the critical range. In the absence of deformation the normalised, i.e., pearlitic, steels, show a gradual spheroidisation of the lamellar carbide with increase of time, and, as is well known, this action increases in rate with rise of temperature. After the time has been sufficient for this carbide to aggregate, graphitisation of the carbide progresses appreciably. It should be noticed that a high rate of spheroidisation and graphitisation is frequently found in steels which have a high rate of creep. This is particularly marked in steels containing a high proportion of silicon to manganese. In the two steels containing about 1.1% of carbon, free cementite occurs in the grain boundaries in a more massive form than that found in the lamellæ. This cementite graphitises at a faster rate than the lamellar form, and this occurs even before the lamellar pearlite is appreciably aggregated. The effect of deformation during the course of creep testing is to accelerate markedly the recrystallisation of the ferrite and the spheroidisation and graphitisation of the carbide. This is particularly noticeable in the highly deformed zone near the fracture. Graphite following spheroidisation is found in the region of the fracture in very long-time creep tests at a temperature as low as 450° C. This temperature is considerably below that at which graphite is formed from the steels without deformation in similar times of exposure. From the nature of the results it is clear that the process of graphitisation is of fairly common occurrence in high-carbon steels heated for long times. The graphitic areas become a source of weakness in the subsequent deformation of the materials.

The mode of deformation in a eutectoid steel at temperatures up to 450–550° C. appears to proceed by a process of dislocation on a plane situated at an angle to the lamellæ of ferrite and cementite. Movement does not appear to take place to more than a slight extent in a direction parallel to the lamellæ. In a steel of low carbon

content deformation tends to occur within the crystals of ferrite. This constituent is weaker than the carbon-bearing pearlite which is also present. Cracks are found in some cases between the ferrite and the pearlite, probably on account of the highly localised distribution of stress between the highly deformed grains of ferrite and the relatively undeformed grains of pearlite. In such cases, however, deformation still occurs in the pearlite by dislocations, which are often spread into zones or bands as the temperature of test is increased. In steels of carbon content higher than that of the eutectoid the presence of free cementite in the grain boundaries constitutes a weakness, and a form of cracking occurs in the cementite in preference to deformation within the pearlite.

The behaviour of the steels at temperatures exceeding the critical range conforms in some of its aspects to the form of cracking found in a material consisting of a single solid solution. grain size tends to coarsen at the testing temperature, perhaps helped by the straining action, but in some cases where deformation has been great, refinement in grain size occurs. Rupture of the specimens is largely influenced by intercrystalline cracking between the austenitic grains, and in the steels of highest carbon content by the gradual formation of graphite, which appears to accelerate this effect. This graphitisation is considerably slower when it occurs from austenite than when it results from the decomposition of cementite at 650° C. It should be remembered that the cementite contains a considerably higher proportion of carbon than that found in any of the austenitic solid solutions considered. probably causes graphitisation of free cementite to occur at a higher rate than that of the austenite. The solubility of graphite in the austenitic solid solution is about 0.8% at 850° and 0.9% at 950° C. These values are lower than those suggested by recent

Apart from the incidence of graphitisation, the other changes which occur within the crystals of austenite are not in any case marked. It should be remembered, however, that on cooling the specimen for examination the pearlite formed from the austenite existing at the testing temperature may mask any minor change.

The work described above was commenced as part of the programme of the Committee on the Behaviour of Materials at High Temperatures of the Department of Scientific and Industrial Research, and was completed as an item of the general research programme of the National Physical Laboratory. The research was carried out in the Metallurgy Department under the direction of Dr. C. H. Desch, F.R.S. This paper is published by permission of the Director of the Laboratory. Dr. G. Barr and Mr. H. R. Sullivan carried out the spectroscopic examination, Miss I. H. Hadfield the microchemical analysis for the graphite content, Mr. T. E. Rooney and Mr. A. G. Stapleton the general chemical

analysis and Mr. H. A. Sloman the analytical work by the vacuum fusion (carbon reduction) method.

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PROTECTIVE PAINTING OF STRUCTURAL STEEL.

BY THE PROTECTIVE COATINGS SUB-COMMITTEE.

Paper No. 5/1941 of the Corrosion Committee (submitted by the Protective Coatings Sub-Committee).

(Figs. 1 to 5 = Plates XIII, to XVI.)

STIMMARY.

An attempt is made in this paper to set out simply the facts concerning the best methods of protecting structural iron and steel work by means of paint. The choice of paint and painting procedures are discussed, but most emphasis is laid on the effect of the surface condition and pretreatment before painting, which are the

most important factors determining success.

The following conclusions are drawn: (1) Maximum durability is achieved by painting over a surface that has been completely freed from mill scale and rust. (2) It is detrimental to allow a surface to rust again between the removal of the mill scale and rust and the application of the paint. (3) Painting over a complete film of mill scale may give good durability in some cases. (4) The life of paint applied to a surface from which mill scale and rust have been incompletely removed is materially reduced.

The following practical recommendations are made: (1) Obtain The following practical recommendations are made: (1) Obtain a good surface free from mill scale and rust. This is best done by pickling, sand-blasting or shot-blasting. (2) Paint- the surface immediately after it has been prepared. (3) Use a corrosion-inhibiting priming paint, such as red lead. Follow this with good weather-resisting finishing coats, such as oxide-of-iron or white-lead paints. (4) Apply all paints under good conditions.

If the painting of new iron and steel structures is carried out with due consideration to the principles outlined above, the saving in maintenance will more than repay the costs of surface preparation before rejuiting.

before painting.

I.—Introductory Remarks.

ALL engineers and users of structural iron and steel work are familiar with the maintenance difficulties arising from the rusting of those materials. Although these problems can be solved in certain cases by the use of rust-resisting steels, the application of such steels is limited for various reasons to a comparatively narrow field, and for the bulk of structural materials it is essential to adopt some method of protecting the iron and steel work from corrosion.

The Corrosion Committee has been investigating these problems since 1928. Its efforts have been directed both towards devising steels that are intrinsically more resistant to corrosion in the unprotected condition and towards improving the methods of protecting iron and steel against corrosive attack. Investigations of the latter aspect of the Committee's work have been intensified under the direction of the Protective Coatings Sub-Committee, formed in 1936.

The Main Committee and subsequently its Sub-Committee have conducted a number of extensive investigations into the problem of protecting steel. Some of the results obtained have already been published in the Committee's scientific Reports and the results of other investigations will appear in due course. The Committee feels, however, that, in view of the vast increase in the output of steel under war conditions, it would not be in the national interest to defer publication of their essential findings concerning the protective painting of structural steelwork, which may be of particular assistance to those who have had no previous experience of this type of production. The Protective Coatings Sub-Committee has, therefore, decided to compile the present statement, in which the practical conclusions deduced from their work in this field are set out in a clear and simple manner. These conclusions are made with particular reference to the most recent series of experiments of the Sub-Committee, which have been undertaken on their behalf by the Research Department of the London, Midland and Scottish Railway Company, Derby, and have now been in progress for rather more than three years. Many of these conclusions are borne out by the results of other series of tests conducted by the Main Committee at seventeen exposure stations in Great Britain and overseas, so that they may be regarded as generally valid for other atmospheric conditions besides those prevailing at Derby.

It is unnecessary to give a lengthy description of the experimental procedure followed in the Derby tests, but it may be noted that the paints were applied to 18×9 -in. panels cut from $\frac{1}{8}$ -in. plates, thus ensuring that the specimens tested were representative of structural material. They were painted on both sides, and exposed on wooden racks at an angle of 45° facing south, as shown

in Fig. 1.

II.—Surface Preparation of New Steelwork.

(a) Importance of Correct Surface Preparation.

The correct surface preparation of steelwork prior to painting is by far the most important factor in determining the success of the protective coating. For example, in one series of tests the life of two-coat paint systems on a correctly prepared surface ranged from 6.8 to 9.0 years, whereas the life of the same systems applied to an incorrectly prepared surface varied from 0.6 to 3.7 years. follows that, whatever steps may be found necessary to speed up production, it is not good practice to skimp the time devoted to



Fig. 1, -General View of the Paint-Testing Station at Derby (L.M.S. Ry, Research Laboratory).

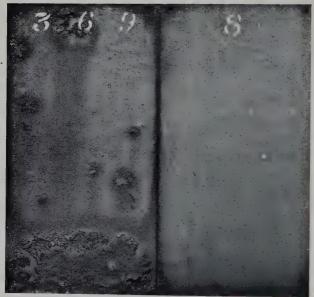
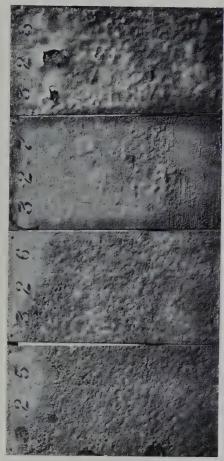


Fig. 2.—Good Surface Preparation Pays. Left: Specimen weathered and hand-cleaned. Righ: Specimen pickled. Both exposed for 3½ years after painting.



Fro. 3.—Artificial Weathering is Useless. As-rolled mild-steel panels exposed out-of-doors for 3 months and sprayed regularly with calcium chloride solution to accelerate the descaling process. Specimens cleaned by scraping and wire-brushing prior to painting. The photograph shows the condition of the paint after 1½ years' exposure.



Fro. 5.—A Corrosion-Inhibiting Primer should be Used. Both specimens pickled and exposed for 34 years after paining. Left: Red-lead primer; the finishing paint, red oxide of iron, shows a few rust spots only. Right: Iron-oxide primer; the finishing paint, white lead + zinc oxide, is 60% discoloured by rust.



Fro. 4.—Do not Delay the Painting. Both specimens pickled. Right: Painted immediately. Left: Expested out-of-doors for 7 days before painting. Both specimens exposed for §§ years after painting. On the left-hand specimen the finishing paint, originally light grey, is 90% discoloured by rust.

surface preparation, since any time or labour saved thereby will be more than wasted later on by the necessity for premature renewal of the protective coating.

(b) Value of Descaling.

Practically all iron and steel used for structural purposes leaves the steelworks with a layer of mill scale on its surface. It has been shown that the presence of this scale under a protective paint film is generally detrimental to the behaviour of the latter. The best procedure, therefore, includes the removal of the mill scale either by pickling or by mechanical means, as described below, before applying the paint. The need for this will be clear from the photographs reproduced in Fig. 2. These show steel panels painted with the same two-coat painting system, in one case after the surface had been descaled properly and in the other after the surface had been allowed to rust and had received no special treatment other than wire-brushing.

(c) Comparison of Various Descaling Methods.

There are three methods for removing mill scale from iron and steel:

(i) *Pickling*, that is, immersion in acid solutions which remove the scale without attacking the metal to any considerable extent; attack on the metal can be reduced to a minimum by adding certain chemical restrainers to the acid bath. Solutions of sulphuric, hydrochloric and, less commonly, phosphoric acid are used for the purpose.

(ii) Sand- or Shot-Blasting, &c.—Included under this head are other mechanical means such as grinding or machining.

(iii) Weathering.—This is the rule-of-thumb method, widely adopted, of exposing the steelwork until sufficient rusting has occurred to render the mill scale loose.

Particular attention was paid in the Derby tests of the Sub-Committee to comparing the effects of these different methods of descaling on the behaviour of paints applied to iron and steel. To this end over 400 painted panels were exposed, which were representative of all commonly used methods of surface preparation; moreover, to ensure reliable results, four different irons or steels and two painting systems were adopted.

Pickling.

Wide variations occur in the conditions of operation of commercial pickling baths as regards the acid used, the temperature and the acid concentration. Consequently, panels prepared by different pickling procedures were tested; the details of the eight most important of these are given in Table I.

Results of the tests to date have revealed practically no differences in the behaviour of paint on surfaces descaled by any of the fresh pickling baths when painting took place immediately after

Table I.—Pickling Procedures Tested.¹

Hydrochloric Acid.	Sulphuric Acid.	Phosphoric Acid.
(1) 2% at 15° C. (2) 10% at 40° C. ² (3) 1% with 8% of dissolved iron at 40° C. ³	(4) 5% at 80° C. ² (5) (a) 5% at 80° C., followed by— (b) 2% phosphoric acid with 0.5% of dissolved iron at 80° C. ⁴ (6) 1% with 12% of dissolved iron at 80° C. ³	(7) 12% at 80° C. (8) 3% with 8% of dissolved iron at 80° C.3

¹ The percentages are by weight.

² Both with and without a chemical restrainer.

To represent a spent bath.
The duplex process.

pickling; further, this behaviour was not affected by the presence of chemical restrainers or inhibitors in the baths. The spent baths, Nos. 3, 6 and 8, gave satisfactory results, but these were slightly inferior to those obtained from fresh baths. Consequently, it may be concluded that, provided that the pickling is properly conducted, the type of acid used and the operating conditions do not, within fairly wide limits, have a marked effect on the results. The main essential is that the strength of the bath be maintained at a sufficiently high concentration to ensure the complete removal of the scale. It is obvious that all free acid and soluble iron salts must be removed from pickled surfaces prior to painting them. This may be done with hot water, but hosing down with cold water is equally efficacious. In some plants the steelwork is immersed in hot lime-water to neutralise the last traces of acid. This procedure has been compared in the present tests with washing in hot water alone; so far the results show that either method gives satisfactory results when carefully carried out, but there is evidence that the use of lime-water allows a greater degree of latitude and does not require so much care.

As discussed later (Section II. (d)), the duplex process, in which the steelwork is rinsed in water after descaling in sulphuric acid and then dipped in dilute phosphoric acid containing iron phosphate, has the advantage of leaving a thin protective film on the surface of the steel; in addition to retarding the development of rust to some extent, this affords a good surface for painting.

91 p

Sand- or Shot-Blasting, &c.

In the Derby tests and in a previous series of experiments, mechanical methods of descaling, such as shot-blasting, proved as effective as pickling in securing a satisfactory surface for paint application. A reservation must be made that in this case it is essential to ensure that all the rust is removed from the surface. This is particularly important when the steel has been previously allowed to rust and presents an uneven, pitted surface; in this case the coarse shot particles may merely bridge the mouths of the pits and hammer the rust into the surface without removing it, and the enclosed rust may, under certain conditions, stimulate further corrosion.

Weathering.

The results of the Derby tests confirm emphatically the conclusions drawn from the work of the Main Committee and of other investigators, that the third method of removing mill scale, i.e., by weathering until the mill scale lifts or flakes off, followed by chipping, scraping and wire-brushing, is most unreliable and, with one exception, the worst method of preparing iron and steel surfaces for painting. In practice, it is impossible to remove the mill scale completely from a large structure by this method, and even with the utmost care much mill scale is left. Not only so, but the process of scale removal is accompanied by the formation of large quantities of rust, a good deal of which remains on the surface despite the most careful cleaning, and which, although not so harmful as mill scale, also has an adverse effect on the behaviour of paint subsequently applied. Further, removal of the scale by weathering has the disadvantage of giving a surface that is rough and pitted as compared with the relatively smooth surface normally produced by other descaling methods, such as pickling; consequently, the appearance of the finished work is inferior.

Since from time to time suggestions are made that weathering should be artificially stimulated by moistening the surface at intervals with various solutions, this procedure was tried in the Derby tests. Specimens were wetted at intervals with a solution of calcium chloride during their exposure in the open, and they were finally wire-brushed before painting. This treatment gave the worst results of all, probably because traces of the deliquescent salt were locked up in the rust remaining in the pores of the surface after wire-brushing (Fig. 3).

(d) Effect of Interval between Descaling and Painting.

The tendency of any freshly descaled iron or steel surface is to rust immediately; this tendency is particularly pronounced in the humid and polluted conditions that are common in Great Britain.

It is logical to conclude, therefore, that the interval elapsing between the removal of the mill scale and painting should be as short as possible, and the experimental results have demonstrated that this is the case. It was found that the best results were obtained when the application of the priming coat was carried out immediately after the pickling and washing process, although storage indoors for periods of up to 30 days did not cause any serious loss of durability; in the latter case, much will obviously depend on the condition of storage. If a good corrosion-inhibiting priming paint is used, satisfactory results can be obtained after short periods of exposure to the weather after pickling, provided that steps, such as scraping and wire-brushing, are taken to remove the loosely adherent rust formed, but such practice should be avoided wherever possible. The effect of exposure to the weather after pickling is illustrated by Fig. 4.

The practical conclusion is that the priming coat of paint should be applied immediately after the descaling operation. Good pickling procedure would consist of rinsing the steel removed from the pickling bath in hot water, allowing it to dry thoroughly as a result of its own heat capacity, and painting it while it was still warm. This procedure should be practicable in many cases; for instance, at one works, plates for tank holders are fabricated, bent and drilled before pickling, treated in the way described and

despatched to the site in a primed condition.

It may be added that there is some evidence that the use of the duplex pickling process (Table I., No. 5) may allow of an increased margin between pickling and painting, owing to the retarding effect of the final immersion in phosphoric acid on the development of rusting.

(e) Surface Washes.

A number of proprietary washes are on the market which, it is claimed, have the power of preventing rusting underneath paint coats, or of neutralising the bad effects of existing rust on a structure that is to be repainted. These washes generally contain phosphoric acid and/or compounds of chromium; one such proprietary wash was included in the tests. It was found to be of doubtful benefit when used on rusted surfaces; indeed, in certain cases, its use led to decreases in the durability of the painting schemes. In other tests, in which inhibitive washes were applied to rust-free surfaces still covered with mill scale, it was found that they led to premature flaking and failure of the paint film; failure occurred on the undersides, which, not being directly exposed to sunlight, often remained wet as a result of condensation.

Therefore, it is the considered view of the Sub-Committee that these compounds cannot be relied on to prevent bad results from painting over mill scale and/or rust; the only safe procedure is to

remove the scale and rust by pickling or mechanical means. In any case it is bad practice to allow steel to rust before painting it.

The use of simple washes containing phosphoric acid may be of value in counteracting the effects of very slight surface rusting, such as may result from a short period of exposure between pickling and painting, but in the Derby tests it was found that such a wash failed to counteract the detrimental effect of 7 days' exposure outdoors in the case of iron and steel specimens carrying mill scale.

(f) Alternative Procedures when Descaling cannot be Adopted.

It has already been stated in Section II. (c) that the common procedure of exposing steelwork to the weather until the mill scale is removed as a result of rusting, cannot be regarded as generally giving satisfactory results. On the other hand, if, for any reason, descaling by one of the other methods described is impracticable, this method may be used, provided that those responsible are reconciled to a greatly reduced life of the initial painting and are prepared to renew the painting after, say, a year's exposure. In this case it would probably be most efficient to apply one or, at most, two coats of paint initially, and clean down the structure thoroughly

before repainting.

It should be added here that as a general principle it is false economy to adopt the attitude that descaling is impracticable or that there is no time for the process, although it is true that the steel-maker or the fabricator may be put to additional trouble or the completion of the work may be slightly delayed by the adoption of descaling. Any increase in expenditure of time or materials is more than offset by the fact that the user of the finished product avoids considerable trouble resulting from the premature failure of the protective coating and possible damage to the structure from corrosion. This is of especial importance in the present national emergency, when it is essential that all protective materials should be used to the utmost advantage, and it should be reiterated that there is no step that will help to ensure this to a greater degree than the initial descaling of the surface.

Another alternative, where pickling or shot-blasting is impracticable, consists in endeavouring to maintain intact mill scale on the steel before painting. This can be done to some extent by taking steps to avoid undue exposure of the steel to the weather and by applying a thin protective coating to the surface at the first available opportunity. Of the available materials none functions so well as red-lead paint. Thick coats of oil should be avoided; they are objectionable, because they set to a hard mass which it is difficult but desirable to remove before the application of the priming coat proper, and which also interferes with marking and welding opera-

tions in the fabricating shop.

It must be realised that surfaces that are completely covered

with intact mill scale cannot be obtained with certainty over large areas under practical conditions, since the mill scale rarely forms a complete covering of the bare metal. There is, too, a tendency for the mill scale to rise in places beneath the paint film, and cause blisters or failures. Hence, although good results may sometimes be obtained by painting over mill scale, the Sub-Committee does not recommend the general adoption of this procedure; in fact, the earlier tests of the Main Committee, which have been in progress for a long period, have shown that it gives worse results than pickling or shot-blasting, although better than weathering.

(g) Treatment of Galvanised Steel or Sheeting.

As a rule, paints do not adhere well to freshly galvanised steel, although they do so to zinc coatings applied by the metal-spraying processes. Consequently, it is necessary to prepare the surface of new hot-galvanised steel before painting it. In order to obtain uniform results, the safest and most rapid method is to etch the galvanised surface, and for this purpose the following solution has been found suitable ¹:

The solution should be applied with an oil-free brush, and after the surface has dried it should be wiped over with a clean dry rag. It is sound practice when artificial etching is not used to allow galvanised steel to weather in the open for some months prior to painting, but it is questionable whether such treatment entirely achieves its object if the period of weathering is restricted. On the other hand, under normal conditions, the painting of new galvanised sheeting can with safety be deferred until it has been in use for some months. The average galvanised sheet carries approximately 0.75 oz. of zinc per sq. ft. of surface; heavier coatings up to practically double this amount can be obtained. The rate of corrosion of zinc in average industrial atmospheres is about 0.2 oz. per sq. ft. per year, so that, in the absence of factors leading to local attack, uniform coatings of the average thickness should last for about four years; in rural atmospheres the life should be several times greater.

Under normal conditions of atmospheric exposure the rate of corrosion of zinc is approximately ten to fifteen times less than that of steel. An exception to this is where the material is exposed in enclosed and polluted conditions, such as railway tunnels, where zinc may be as corrodible as steel. Apart from the increase in the corrosion resistance of the surface, the use of galvanised steel or sheeting as compared with that of non-galvanised material has the

¹ Difficulty may be experienced in obtaining the solvents required for this solution in the present emergency.

great advantage of ensuring that the paint is applied over a good surface, free from rust, and that the painting can be carried out as

labour becomes available.

Although the Sub-Committee's experiments in this field are still in an early stage, attention may be drawn to the undoubted usefulness of sprayed-metal coatings, particularly of aluminium and zinc, in conjunction with paints; more use of this method of protecting steel will undoubtedly be made in the future.

The question of priming paints for galvanised steel is discussed

in Section III. (b).

III.—CHOICE OF PAINTS FOR NEW STEELWORK.

(a) False Economy of Cheap Paints.

An analysis of the costs of protective painting will often show that the cost of the paint forms only a small proportion of the total costs, especially in the case of the painting of completed structures, where the costs of cleaning and scaffolding are often paramount. The ratio of these costs to the cost of the actual paint materials will naturally vary from one job to another, but as an illustration it may be noted that in the case of some steel exposure stands used by the Committee the cost of labour for cleaning and painting was 6.2d. per sq. ft. as compared with 0.55d. per sq. ft. for the paints themselves. This gives a ratio of 11 to 1, and, regarded from this angle, even appreciable differences in the price of paints per gallon will be seen to have but a small proportional effect upon the painting costs. The choice of paints, therefore, should not be made solely on a price basis, quality or protective power being the first criterion. In this connection it has been shown by other investigators that the addition of unlimited amounts of extenders (that is, of pigments chosen for the purpose of cheapening the paint) to red-lead paint has a deleterious effect upon the protective value of the paint when the quantity added exceeds a maximum percentage. Certain pigments, however, are sometimes added for technical reasons—for instance, to prevent settling or to ease application—and, provided that care is used in the choice of the additional pigment, it is often sound practice to do this. For example, one large commercial concern specifies that a red lead and graphite mixture shall be used as a priming paint instead of pure red lead. They claim that this has the advantage of reducing the weight of the paint per gallon from between 28 and 32 lb. to about 20 lb. and is accompanied by much greater ease of application and the absence of settling. Indeed, although what has been said concerning the uncontrolled admixture of extenders with red-lead paint can be generally applied, often a paint containing mixed pigments is superior to one containing any one of them singly.

(b) Value of Corrosion-Inhibiting Primers.

All the painting tests conducted by the Main Committee and its Sub-Committee have agreed in showing that the best results are obtained when the paint applied directly to iron and steel is pigmented with materials that repress the tendency of the steel surface to corrode; paints of this type are known as "inhibitive" paints. For example, in the Derby tests it has been found that specimens painted with one coat of red-lead primer and one coat of red-oxideof-iron finishing paint have been more efficiently protected than similar specimens painted with one coat of red-iron-oxide primer, and one coat of white lead + zinc oxide finishing paint; this is evident from Fig. 5.

The following pigments are known to have inhibitive properties: Red lead, white lead, lead chromate, blue lead (basic sulphate of lead), zinc chromate and other sparingly soluble chromates, zinc dust and possibly zinc oxide. The Committee's tests have shown that the most effective of these primers for general use is red lead and that chromate pigments are not on the whole quite so good; they give good protection in rural and marine atmospheres, but are inferior to red lead in industrial atmospheres. The relative efficiency of the remaining pigments has not been established with certainty.

A few suitable formulations are given in Table II. The numbers of the normal and the war-emergency British Standard Specifications relating to the pigments and other ingredients will be found in Table III.

There is no point in priming galvanised sheets with red-lead paint unless they have been damaged or so badly corroded as to expose the steel base, since the zinc coating itself inhibits the corrosion of steel. Prepared tars and bituminous paints often give

Table II.—Compositions of Corrosion-Inhibiting Priming Paints for Iron and Steel.

	Red Lead.	White Lead.	White Lead and Zinc Oxide.	Lead Ohromate.	" Blue Lead."	Red Oxide and Zinc Chromate.
Pigment	80	77	78 1	66	90 2	69 ⁸
Refined linseed oil Boiled linseed oil	14	6	9	16	5	13
Turpentine .	1	12 4	9	16	4	13
White spirit . Driers	1	···	3	2	1	2 3
	.,			-		0

White lead 52%, zinc oxide 26%.
 This pigment is obtained by the controlled oxidation of galena; approximately one-half consists of lead sulphate, one-third of lead monoxide and the remainder of lead sulphide, zinc oxide, &c.

³ Red oxide of iron 53%, zinc chromate 16%.

good results on properly prepared galvanised sheets, but if an oil paint is required red oxide of iron can be used.

Table III.—British Standard Specifications for Paint Materials Listed in Table II.

Material.	Normal,	ormal. War Eme		
Red lead White lead Zinc oxide	B.S.S. No. 217 239 254	Date. 1936 1935 1935	B.S.S. No.	Date.
Red oxide	282 272 Natural 305 Manufactured 694 Blended	1936	927	1940
Zinc chromate. Linseed oil: Raw. Refined Boiled linseed oil. Turpentine: Type 1.	389 243 242 259 244	1938) 1936) 1936) 1936)	925	1940
Type 2. White spirit	290 245	1936 1936 1936	925	1940
Driers: Liquid . Paste	332 331	$1938 \}$	925	1940

(c) Finishing Paints.

The best general finishing paints available in quantity for use over red lead are red oxide of iron, white lead or micaceous iron ore. During the war emergency particularly, alternatives to the linseed-oil paints mentioned should be considered; chief amongst these will be tar paints. The merit of tar, especially in coastal and marine conditions, has already been established, and the extended use of tar should be considered as a means of reducing imports, while at the same time maintaining the protection of structures undiminished. Red lead and tar used in combination provide excellent protection; one coat of red lead followed, after an interval of not less than one month, by one coat of tar which has been neutralised with lime and treated with tallow is a scheme which has been used with much success.

(d) Paints for Underwater or Underground Work.

Painting procedures and the choice of paints for underwater or underground work do not come within the general scope of this paper, which relates solely to protection against atmospheric corrosion. These subjects are, however, being investigated by other Sub-Committees of the Corrosion Committee, namely, the Marine Corrosion Sub-Committee and the Sub-Committee on the Corrosion of Buried Metals.¹ It is hoped that in due course these Sub-Com-

¹ The latter Sub-Committee is working in collaboration with the Committee on Soil Corrosion of Metals and Cement Products of The Institution of Civil Engineers.

mittees in their turn will be able to issue similar recommendations for the protection of steelwork in these other fields of service.

IV.—PAINTING PROCEDURE.

(a) Importance of Good Painting Conditions.

In order to obtain the best results all painting should be carried out under dry conditions when the air is reasonably warm, say, 60° F. or more, and the humidity is not unduly high, say, below 90%. If possible, the operation should be conducted under cover; this clearly cannot be done when repainting existing structures in the open, but, with few exceptions, there is no reason why the initial priming coat of structural steelwork should not be applied under cover.

It is obvious that difficulties must arise in applying these considerations in practice and that it may sometimes be impossible to adhere to them closely, particularly under war conditions. Nevertheless, in many cases, by giving a little thought to the matter, much can be done to ensure that the painting of steelwork takes place under favourable circumstances. Any little extra trouble taken in this way will be more than repaid by the better results obtained.

(b) Spray versus Brush Application.

It is difficult to give a final answer to the question whether spray-painting or brush-painting gives the better results. The fact is that a strict comparison of the two methods of painting is not always possible. As regards speed, in the majority of cases the advantages undoubtedly lie with spraying; on the other hand, it has to be appreciated that certain types of lead paints are only suitable for brush application. As against this, other types of materials, such as cellulose finishes, are best suited to spray application. It is possible, within the types of paint normally employed in the painting of structures, to obtain a more uniform coating by spray application than by brush, and there is abundant evidence to show that brush marks in films applied by brush constitute sources of relative weakness in the film as a whole.

The discussion may be summed up by the statement that the best practical results will be obtained by making intelligent use of both processes.

V.—REPAINTING OF OLD STEELWORK.

(a) Excessive Deterioration of Old Paint to be Avoided.

It has been shown in Section II. (a) that the guiding principle for ensuring success in protection by painting is that no rust should be allowed to form beneath the original coat of paint; the same principle holds good so far as repainting is concerned. In other words, an

existing paint film on structural steel should never be allowed to deteriorate to such an extent that rusting occurs beneath it, for, if this happens, extensive cleaning-down and scraping to the bare metal will be necessary. Moreover, since it is impracticable to pickle an erected structure, a clean metallic surface will be unobtainable (unless, of course, shot-blasting is resorted to, which is costly and not always practicable 1). This means that the coating applied on repainting will have a shortened life; in fact, the evil may not be completely eradicated until the structure has been repainted several times.

As soon, therefore, as the paint film itself begins to show signs of failure, whether by chalking, cracking, blistering or under-rusting, an additional coat of paint should be applied over it. If failure is adjudged to have occurred as a result of blistering or under-rusting, the latter of which will be revealed by rust stains, care should be taken to make sure that the old paint film is perfectly sound and adherent; if not, it should be removed. It must also be borne in mind that the development of chalking is a natural process in the weathering of certain paints, and does not necessarily mean that they have lost their protective value to the extent of justifying repainting. If corrosion has occurred in isolated places, the surface should be cleaned down as thoroughly as possible and primed with an inhibitive primer; these areas might with advantage receive an additional coat of finishing paint. Paint in a sound condition should not be unnecessarily removed.

(b) Surface Preparation and Cleaning Tools.

If, as should be the case, the old paint film is firm and adherent, no elaborate surface preparation is necessary; in the optimum case, a simple washing-down with bristle brushes and clean water should suffice. The paint should naturally be allowed to dry thoroughly before the new paint is applied. If the paint film is sound but contaminated with oil or grease, it should be wiped with

a rag dipped in white spirit to remove them.

If deterioration of the old paint film has been allowed to take place and actual rusting has occurred, it may be necessary to remove the old paint as well as the rust. A flame-descaling process may be useful in this connection; in essentials this consists in burning off the paint with a wide, multi-jet oxy-acetylene burner, which is passed over the surface of the structure. The steel is heated and is painted while it is still warm. Although final experimental evidence is not yet available, there is reason to believe that the deleterious effect of any remaining rust is diminished by this treatment.

Failing these methods, resort must be had to hand-cleaning by means of hammers, scrapers and wire brushes, which is an expensive

¹ As indicated in Section II. (c), even shot-blasting may not be entirely satisfactory if the surface is heavily rusted.

process when effectively carried out. The operation can be facilitated by the use of mechanical tools, such as portable grinding wheels and wire brushes.

(c) Types of Paint to be Used.

If it is necessary to remove the old paint film it will clearly be advisable to use the same painting system as that used for initial painting, *i.e.*, give one or two priming coats of inhibitive paint followed by one or two coats of finishing paint; the process should normally consist of not less than three coats but preferably four.

If the old paint is sound it will be unnecessary to apply any further inhibitive paints, except to bad areas as mentioned in Section V. (a). In general, one or two coats of paint may be applied, which should be similar in composition to the original finishing paints.

VI.—SPECIAL CASES.

(a) Paints for Anti-Glare Structures.

Considerable trouble is experienced from the corrosion of structural steelwork and steel sheets used for the structures erected over blast-furnaces, coke-ovens and the like in order to prevent the emission of glare from these plants during black-out hours. This results from the fact that the steel is subjected to high concentrations of corrosive gases and steam at temperatures well above the normal. The combination of corrosive gases and elevated temperature is such as to cause breakdown of many of the most usual protective coatings and premature failure of the sheets.

The Committee has been investigating the problem and has made progress in the choice of suitable protective coatings for the

purpose.

It would be inexpedient to give details of the results in a publication such as this, intended for general circulation, but the information obtained will be made available to any bona fide engineer or works manager experiencing trouble from this cause. Enquiries should be addressed to the Secretary of The Iron and Steel Institute.

INVESTIGATION OF THE INFLUENCE OF MOULD FRICTION ON TEARING IN CASTINGS.¹

By Professor J. H. ANDREW, D.Sc., and H. T. PROTHEROE, B.Sc. (The University of Sheffield).

(Figs. 1 to 10 = Plates XVII, to XIX.)

Paper No. 2/1941 of the Steel Castings Research Committee.

SUMMARY.

The "bulk" resistance of sand to the contraction of steel has more effect on the tearing of steel castings than the friction between

contracting steel and the actual sand grains.

Long steel bars were cast in various grades of sand in a series of boxes, which enabled different volumes of each grade of sand to be employed. The degree of tearing varied with varying bulks of sand, being more severe as the bulk of sand surrounding the casting was increased, but castings rammed in coarse sand did not tear any more severely than castings made in fine sand. By using sloping runners, the slight ease given to the contracting casting against the bulk resistance of the sand was sufficient to prevent tearing.

An attempt to obtain the temperature at which the castings

cracked is briefly described.

THE disastrous effect of the hot tearing of steel castings of complicated design is well known and is generally attributed, amongst other things, to the resistance offered by the sand to the contraction of the casting, with the result that such methods as digging away sand from the region of runners and feeder heads, construction of collapsible cores, &c., are resorted to. Such methods constitute so far the only means by which this tearing is minimised and very often prevented altogether. It is not hard to see that in some castings even these simple preventatives, although applied, cannot be expected to be fully effective, and the steel founder has then to rely on the skill of the welder to make his castings acceptable.

During contraction, particularly solid contraction, the casting must obviously move, if only ever so slightly. In the case of complicated box-like castings this contructional movement is uniform in neither rate nor direction. The former depends on the uniformity of temperature, and the latter on the design of the casting, the location of cores, &c. The actual position of the resulting "tear" is that portion of the casting which, at the moment when these con-

¹ Received May 29, 1941.

tractional stresses and sand resistances cannot be resisted further, is the weakest-namely, the hottest position. Coupled with this resistance, offered to the contracting casting by the body of the sand itself, is the possibility that there is actual friction between the sand grains and the surface of the casting. If this mould friction is great then the normal movement of the casting is further restricted and the liability to tearing is augmented.

INVESTIGATION.

The following series of experiments were devised to uphold or disprove the contention that mould friction is a contributory cause to the tearing of steel castings. To eliminate such factors as nonuniformity in the direction of contraction, the pattern selected for these experiments was a simple bar 4 ft. long, 12 in. wide and 3 in. These dimensions were finally decided upon after a few preliminary experiments with a bar 4 ft. long, 2 in. wide and 3 in. thick had failed to give anything but sound castings.

The first series of experiments was conducted using a two-part

moulding box of the following internal dimensions:

Top part: 4 ft. 6 in. long, $7\frac{1}{2}$ in. wide, 3 in. deep. Bottom part: 4 ft. 6 in. long, $7\frac{1}{2}$ in. wide, $3\frac{3}{8}$ in. deep.

The actual casting was located in the bottom box, so that with the above dimensions it was ensured that the casting was completely surrounded by a uniform body of sand, that is, 3 in. (All experiments conducted in this box are indicated by the prefix S_2 .) resistance to contraction as a result of the body of the sand was thus, in all cases, uniform, and any variations in this resistance when using different sands, it was thought, would be due entirely to variations in the degree of mould friction.

Three bars in each of three different sands were made, using this moulding box. The mechanical analyses of the sands were conducted in a Crook elutriator used in conjunction with a Boswell elutriator. The former, after sieving to 1 mm., separated the sand, silt and clay, the sand portion being graded further in the Boswell elutriator.

Table I. gives the grading of each sand in accordance with

Boswell's classification.

Table I.—Grading of each Sand in accordance with Boswell's Classification.

Sand.	Very Coarse Sand (>1 mm.).	Coarse Sand (0.5-1.0 mm.). %.	Medium Sand (0.25-0.5 mm.). %.	Fine Sand (0·1-0·25 mm.). %.	Silt (0·01-0·1 mm.). %.	Clay (<0.01 mm.). %.	Total Sand.
A B C	4·2 26·4	21·6 54·3	18·4 70·8 9·5	77·0 2·0 7·7	2·6 1·3 0·3	1·8 0·9 2·0	95·4 98·6 97·9

It will be noticed that the sand can be designated fine, medium and coarse. In each case the silt portion was very small, so that

it was decided not to separate into coarse silt and fine silt.

In all the experiments the sand received the same treatment, that is, adding the bentonite, milling dry for 5 min., adding the moisture and then milling for a further 10 min. The moisture was kept at approximately 4.5% in each instance. The amount of bentonite added was 5%, and all the bars were cast in green sand.

As previously stated, the whole of the casting was located in the bottom box, the runner and riser being contained in the top half.

Fig. 1 is a photograph of the casting obtained.

Immediately before pouring, the casting temperature was obtained by means of a tungsten-molybdenum immersion couple. Each casting was allowed to remain in the box for the same length of time before being knocked out and was then examined in the following manner:

The extent of tearing was first noted, Figs. 2 and 3 being chosen



Fig. 11.—Manner of Sectioning Castings to obtain sulphur prints and micrographs.

as representative of typical tears. In the case of the latter the two portions of the casting were barely joined when the box was stripped, and this is typical of the most severe tearing obtained. Fig. 2 is typical of the type of tear obtained in the majority of the castings. In three instances only, which are referred to in Table III., was

the tearing less severe than that shown in Fig. 2.

The casting was then cut into eight portions, as indicated in Fig. 11, the surface of each portion being suitably prepared in order to obtain sulphur prints. It was afterwards re-ground and repolished and given a neutral etch with copper-ammonium-chloride, it being hoped that the grain size would indicate any variation in the rate of cooling throughout the length of the bar. Unfortunately, the etching did not show this, therefore, after the first half-dozen or so bars were examined in this way this treatment was discontinued.

The sulphur prints were substantially the same in each instance and only two samples, picked at random, are shown in Figs. 4 and 5. It will be noticed that there is a decided sulphur segregation near the runner and riser ends of the casting. As is pointed out later, however, it is not thought that this phenomenon is a contributory

factor to the tearing of the bars.

Micro-sections were taken from each bar from the regions indi-

cated in Fig. 11, and as these in all instances showed no useful result, only two are shown in Figs. 6 and 7.

Table II. summarises the results of series S_3 .

A minor point of practical importance was noticed in regard to bar S_31 . Being one of the bars of which a macrograph was obtained, it was noticed that over the whole length of the bar small nests of blow-holes were situated at regular intervals, corresponding to the position of the cross bars in the top box. This was the result of

Table II.—Series S₃.

Sand. Bar No.			Analysis.*		Casting	Remarks.
		O. %.	Si. %.	Mn. %.	Temp. °C.	Technology
A	S_3 1	0.40	0.20	1.22	1510	Cracked, as Fig. 2.
	S_3^2	0.31	0.3	0.7	1530	']
	S_3 3	0.29	0.31	0.73	1540	
B	$S_34 \\ S_35$	0.30	0.30	0.70	1520	
	S_35	0.31	0.29	0.68	1550	Cracked, similar to
	$S_3^{\circ}6$	0.32	0.31	0.71	1520	$S_31.$
C	S_37	0.29	0.30	0.68	1535	
	$S_3^{-}8$	0.33	0.31	0.71	1515	
	S_39	0.32	0.29	0.71	1546	
	S ₃ 9	0.32	0.29	0.71	1546	<u> </u>

^{*} Sulphur and phosphorus in all casts between 0.03 and 0.035%.

using the vent wire too far away from each cross bar. In subsequent casts the vent wire was driven down the side of each cross bar directly over the pattern, and no further blow-holes occurred.

A second series of experiments was conducted, using the same three sands as before but with moulding boxes of the following

dimensions:

Top part: 4 ft. 8 in. long, $9\frac{1}{2}$ in. wide, 4 in. deep. Bottom part: 4 ft. 8 in. long, $9\frac{1}{2}$ in. wide, $4\frac{3}{8}$ in. deep.

(All experiments conducted in this box are indicated by the prefix S_4 .)

The results are summarised in Table III.

Casts S_4 1, S_4 4 and S_4 5 are the three casts referred to above which did not crack so severely as the majority of the castings.

No satisfactory explanation can be given.

By using these larger S_4 boxes the body of sand is increased by 1 in. all round, and it was thought that the increased resistance to contraction offered by a larger body of sand would be shown by a more severe type of tearing. Actually this was not so, and with the exception of S_4 4 and S_4 5, the nature of the tearing was the same as in the S_3 series.

It was suspected by this time that tearing occurred regardless of



Fig. 1.—A Casting as Stripped from the Moulding Box, showing tear at runner end.



Fig. 2.—Type of Tear obtained in the Majority of Cases.



Fig. 3.—The Most Severe Type of Tearing.

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Figs. 4 and 5.—Typical Sulphur Prints.

[Andrew & Protheroe.



Figs. 6 and 7.—Typical As-Cast Microstructures.



Fig. 8.—Casting with Sloping Runner and Riser.



Fig. 9.—Tear obtained with Ordinary Method of Casting, but with no cross-bars in the top box in close proximity to the runner or riser.



Fig. 10.—Some Castings made with Sloping Runners and Risers.

(Micrographs reduced to two-thirds linear in reproduction.)



TABLE III.—Series S4.

Sand.	Sand. Bar No.		Analysis.		Casting Temp.	Remarks.	
		C. %.	Si. %.	Mn. %.	° C.	itemains.	
A	S_4 1	0.23	0.17	0.8	1540	Cracked, but not quite so severely as S_3 1.	
	S_42 S_43	0·34 0·30	$0.20 \\ 0.22$	0·74 0·63	$1530 \\ 1525$	Cracked similarly to S_31 .	
В	$S_4 4 \\ S_4 5 \\ S_4 6$	0·23 0·34 	0·17 0·20 	0.8	1530 1530 1545	Cracked, less than S ₄ 1. Only slightly cracked. Not a successful cast. There was a run-out near the runner, and mould did not fill. Even so the bar cracked slightly.	
C	S_47	0.32	0.31	0.6	1550	Cracked similarly to Fig. 3.	
	S_48 S_49	0·30 0·28	$0.28 \\ 0.31$	0·71 0·8	1528 1510	Cracked similarly to S_31 .	

the *nature* of the sand. Castings produced in the coarse-grained sand did not tear any more severely than those produced in the fine-grained sand. Mould friction therefore, if at all contributory to this tearing, was only so to a very small degree.

It was assumed that body or bulk resistance of the sand was the chief factor. Consequently the volume of sand surrounding the casting was further increased and a series of experiments commenced

using boxes of the following dimensions:

Top part : 4 ft. 10 in. long, $11\frac{1}{2}$ in. wide, 5 in. deep. Bottom part : 4 ft. 10 in. long, $11\frac{1}{2}$ in. wide, $5\frac{3}{8}$ in. deep.

This added volume of sand definitely had an effect. The tearing was more severe than in the S_3 or S_4 series. In a few instances the final bar was only just joined together. Fig. 3 is a photograph of bar S_5 1, which so severely cracked that it parted when being lifted from the box.

The results are shown in Table IV.

It was realised at this stage that it would be of great assistance if more definite information could be obtained regarding the precise moment at which tearing occurred, and the temperature of the casting at this moment. After one or two unsuccessful runs a method was devised whereby the temperature of the bar could be recorded almost from the time of casting. A tungsten-molybdenum couple was constructed and inserted in the mould as indicated in Fig. 12. The couple was protected by an outer alundum sheath, and the wires were insulated from each other by encasing one wire

TABLE	IV.—	-Series	S_5 .
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Sand.	Sand. Bar No.		Analysis.			Remarks.
		O. %.	Si. %.	Mn. %.	Temp.	
A	S_51	0.31	0.29	0.7	1548	Cracked severely.
	$egin{array}{c} S_5 2 \ S_5 3 \end{array}$	0·30 0·33	$\begin{array}{c} 0.30 \\ 0.29 \end{array}$	$\begin{array}{c c} 0.67 \\ 0.80 \end{array}$	$\begin{array}{c} 1520 \\ 1524 \end{array}$	Cracked not quite so severely as S_51 .
B	$S_{5}4 \\ S_{5}5 \\ S_{5}6$	0·34 0·36 0·28	0·31 0·33 0·31	0·7 0·66 0·70	1550 1530 1525	Cracked similarly to S_51 . Cracked similarly to S_52
C	S ₅ 7 S ₅ 8 S ₅ 9	0·38 0·30 0·32	0·29 0·32 0·30	0·72 0·69 0·74	1510 1538 1518	$ \left. \begin{array}{l} \text{Cracked similarly to } S_5 1. \end{array} \right. $

in a fine-bore silica sheath. A hole was cut in the moulding box, through which the couple was inserted into the outer sheath which had been placed in position during ramming. This outer sheath was insulated from the sand by wrapping in mica sheet.

It was found essential to insert the end of the thermocouple in the stream of metal entering the mould. This served to raise the alundum sheath to the temperature of the metal before the mould was completely filled. The time lag was thus reduced to a minimum. In previous attempts the thermocouple was inserted in the centre of the bar, through the bottom, and it was found that the time lag was

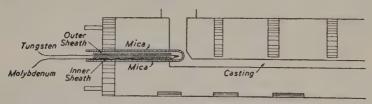


Fig. 12.—Method of Inserting the Thermocouple in the Mould.

too great. Actually the thermocouple did not commence recording until the bar had cooled to about 900° C.

A few attempts have been made to determine at what temperature the bar cracked by using this thermocouple in conjunction with a resistance circuit. The bar was incorporated in the circuit as indicated in Fig. 13. After the pattern had been withdrawn from the mould, two mild steel rods, which had been previously cleaned, were inserted so as to project about ½ in. into the actual mould. Suitable notches were cut in the edges of the bottom box in order to take the rods. These were insulated by means of mica sheet, and served

as connections between the bar and the leads which completed the circuit.

It was assumed that the severe tearing of the casting would have an effect on the conductivity of the bar, which would be shown by an increase in resistance. This method, however, is not sensitive enough, and the slightest connection between the two portions of

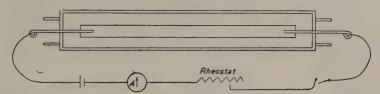


Fig. 13.—Method of Incorporating the Casting in an Electrical Circuit in an attempt to determine the temperature at which the castings cracked.

the bar is sufficient to carry the current from a 2-volt accumulator. Increasing the current did not prove any more satisfactory, and the

project was abandoned.

At this stage it had been definitely concluded that it was the bulk resistance of the sand to the contraction of the casting which caused the tearing. Further, every bar without exception cracked at the runner end. By the sluggishness of the metal rising through the riser it was realised that there was a marked temperature gradient from riser to runner. It follows that the direction of contraction is parallel to the length of the bar from riser to runner, as indicated in Fig. 14. The contraction along the width of the bar is relatively

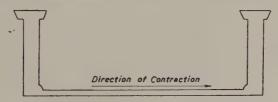


Fig. 14.—Direction of Contraction of the Castings.

much smaller and can be ignored. The obvious remedy to alleviate tearing was realised a very long time ago, and is still in use at the present time. That is, the digging away of the sand from the region of the runner and riser. A method not quite so obvious is to slope the runner and riser. Fig. 8 is a photograph of a casting produced with sloping runner and riser. It was made in the S_3 box using sand C, and is perfectly sound. When sloping in this manner both the runner and riser slide with the casting during contraction, and the contraction stresses are sufficiently relieved to prevent tearing.

To permit of each runner and riser to fit in the box it was necessary to knock out a bar from each end of the moulding box. It was realised that the absence of these bars from close proximity to runner and riser might in itself be sufficient to ease the strain due to the resistance of the sand, and consequently another casting was made by the ordinary method using the same box minus these two bars. Fig. 9 is a photograph of the tear which resulted. A further series of bars using sloping runners was made with different boxes, varying the sand each time. All the bars obtained were sound and no indication of tearing was observed. The number of bars made is indicated below, and Fig. 10 shows photographs of some of these bars.

These experiments with sloping runners were continued in a

slightly modified manner.

The angle of slope was varied from 30° to 80° and the bars were cast in the boxes used for series S_4 . Six bars were cast in all with the runners sloping at 30° , 40° , 50° , 60° , 70° and 80° . Each bar was sound. It appears therefore that in castings of such small dimension the slightest slip is enough to ease the resistance to construction sufficiently to prevent tearing.

CONCLUSIONS.

From the large number of tests carried out it would appear that hot tearing is due rather to the resistance offered to contraction by the bulk of sand than to the nature of the sand itself. When steel castings are stripped from the box, it is observed that there is a thin layer of burnt sand between the face of the casting and the main body of the sand. This layer is very friable and, provided the refractoriness was originally sufficient, it is easily removable from the casting. However, after being submitted to a temperature as high as that of molten steel, there is no strength in this sand. It is not likely, therefore, that there is any resistance offered to the contractional movement of the casting. It is quite possible, on the other hand, that the friction between molten metal and the sand increases with increase in coarseness of the sand. This was observed when casting at the same temperature in different sands. In the case of sand C, metal cast at the same temperature appeared to take longer to fill the riser than when cast in sand A. The head of metal in each case was the same, but the rate of pouring was not controlled. which might account for it.

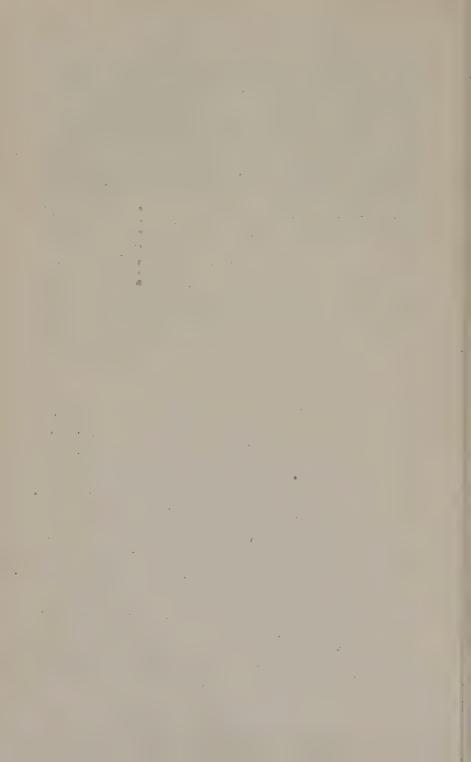
No attempt is made to explain the sulphur segregation near the runner and riser, but it is felt that the temperature at the crucial moment during contraction will decide where the casting tears.

In every test carried out this was near the runner, that is, in the hottest region. Given uniformity of temperature, the bar is quite as likely to crack near the riser as near the runner. The degree of purity might possibly influence the location of the tear in this case.

With regard to casting temperature, the only deduction possible from the varied number of casting temperatures employed is that tearing occurs some time after solidification, probably very soon afterwards. It is known that at such temperatures steel is very weak, and it is also known that metals contract at a quicker rate at elevated temperatures than at lower temperatures. These facts when taken together indicate that tearing occurs somewhere near the solidification temperature.

It has been shown that, provided one runner is set at a sloping

angle, hot tearing will not occur.



THE POSITIONS OF THE CARBON ATOMS IN AUSTENITE.*

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SUMMARY.

By careful photometric work direct X-ray evidence of the location of the carbon atoms in austenite has been obtained. They are found to lie at the centres of the unit cells and at the midpoints of the edges, these positions being the centres of the largest 'spaces between the iron atoms in the austenite structure.

There is never enough carbon in solution for every one of these positions to be filled. The number of carbon atoms per unit cell varies from zero for pure iron to 0.32 for a 1.7% carbon steel, so that, at the most, only one possible position in twelve is occupied.

that, at the most, only one possible position in twelve is occupied.

Other theories of the structure of austenite are discussed in the

light of these results.

Introduction.

SINCE austenite is formed by the solution of cementite in y-iron, it was perhaps natural for the idea to arise that the cementite retains its identity to a certain extent in solution. But when X-ray work supplied a knowledge of the positions of the iron atoms in the various phases of the iron-carbon system the objections to this idea became obvious. In y-iron (1) the iron atoms form a facecentred cubic structure, whereas in cementite (2) they form a complicated orthorhombic structure. There is no possibility of austenite consisting of a γ-iron structure with the cementite structure fitted into it. Instead, when cementite dissolves in y-iron there must be an atomic rearrangement such that all the iron atoms, whether derived from the pure iron itself or from cementite, situate themselves on a face-centred cubic lattice. What happens to the carbon atoms is a more difficult problem to solve directly by X-rays because of the low scattering power, but some progress has been made by other methods. Westgren (1) has shown by density considerations that the carbon atoms do not lie on the same lattice as the iron atoms. This follows also from the fact that the addition of carbon increases the size of the unit cell, corresponding to a progressive pushing apart of the iron atoms by the insertion of carbon atoms between them. If the small carbon atoms had replaced iron atoms on the lattice they would cause a decrease in the cell size.

All this evidence is, however, indirect, and the interesting question of the precise arrangement of the carbon atoms in the interstices of the iron lattice is left open. If the forces which hold the structure

^{*} Received September 17, 1941.

together tend to keep it as close-packed as possible, it might be expected that the carbon atoms would go where they would cause the least deformation. If, however, the forces between the carbon and iron atoms have directional tendencies, such as are observed in covalent bonding, the carbon atoms may be forced into other positions. A distribution of the carbon atoms, some in one type of interstice and some in another, would be possible only if the two positions had the same free energy, and this is unlikely.

It is of particular interest to see if the positions show any resemblance to those in cementite, in which the carbon atoms are at the centres of triangular prisms of iron atoms.⁽³⁾ Though this arrangement of iron atoms does not occur in austenite, deformed prisms may be considered to be present, and the carbon atoms might be

found at the centres of these.

The object of the present work was to obtain the direct experimental evidence of the location of the carbon atoms which has hitherto been lacking.

Spatial Considerations.

The interstices available have their middle points at the centres of either regular octahedra, regular tetrahedra, or equilateral triangles of iron atoms. These spaces are listed in the order of their size, but in the inverse order of the number present in the unit cell.

Johansson (4) puts forward as evidence that the carbon atoms are in the octahedral positions the fact that if the cell volume is calculated, using the known atomic radii and assuming that there is a carbon atom at the centre of each octahedral interstice, then the result agrees with the value obtained by linear extrapolation of the observed cell volumes to this carbon content. Such evidence is unsatisfactory. If the extrapolation of the observed values is carried out to the carbon content corresponding to either all the octahedral, all the tetrahedral or all the triangular spaces having carbon atoms at their centres, then it is found that the iron-carbon distances are 2·13 Å., 2·05 Å. and 2·44 Å., respectively. The usual distance is 2.03 Å. These austenite values cannot be considered completely reliable, because it is unsafe to assume linear extrapolation over the large range required, for example from 1.7% to 17.7%of carbon for the octahedral interstices. Allowing for this limitation, the evidence cannot be said to favour any particular one of the three possibilities. It is impossible to avoid these uncertainties due to extrapolation by making calculations at the carbon contents for which the lattice parameters can be measured. At these compositions there are not enough carbon atoms for every interstice to be filled, and the resulting dimensions cannot be calculated theoretically without making arbitrary assumptions.

To sum up, it may be said that by purely spatial considerations it is impossible to obtain any definite evidence of the carbon positions.

X-Ray Intensity Evidence.

Theoretically it should be possible to obtain direct location of the carbon atoms by X-ray methods, but in practice there is the difficulty that the carbon atoms are so light that they have little effect on the intensity of the X-ray reflections. In addition, the accuracy of measurement of intensities is limited by the possibility of errors due to lack of uniformity in the film, irregular development and inaccuracies in photometry, &c. Consequently this method has not previously been used to locate the carbon atoms.

The intensity of an X-ray reflection involves a structure ampli-

tude F_{hkl}^2 :

$$F_{hkl}^2 = (\Sigma f \cos 2\pi (hx + ky + lz))^2 + (\Sigma f \sin 2\pi (hx + ky + lz))^2$$

where f is the scattering factor of each of the atoms present and x, y, z are the atomic co-ordinates expressed as proportions of the corresponding cell edges. The summation extends over all the atoms within the unit cell. By this means it is possible to calculate the effect of the carbon atoms in various positions on the intensities of the lines. The results of such calculations for an austenite containing $1\cdot 4\%$ of carbon are shown in Table I. The atomic scattering factors used are those given in the International Tables. (5)

Table I.—The Theoretical Influence of Carbon Atoms at the Centres of the Various Interstices on F² for a 1·4% Carbon Steel.

		Carbon Effect on							
			F ² ∇	alues.			rox. percent		
hkl.	Line.	Interstic			ice— Interstice		Interstice—	_	
		γ-Fe.	Octahe- dral.	Tetrahe- dral.	Tri- angular.	Octahe- dral.	Tetrahe- dral.	Tri- angular.	
111	3	4911	4818	4911	4899	-2	0	0	
200	4	4246	4327	4165	4206	+2	-2	-1	
220	8	2903	2958	2958	2917	+2	+2	0	
311	11	2409	2361	2409	2421	-2	0	0	
222	12	2277	2324	2231	2271	+2	2	0	
400	16	1870	1910	1910	1850	+2	+2	· -1	
331	19	1665	1630	1665	1647	-2	0	—I	
420	20	1594	1627	1561	1602	+2	-2	0	
422	24	1348	1379	1379	1345	+2	+2	0	
$\left[\begin{array}{c}511\\333\end{array}\right]$	27	$\left\{ {1219 \atop 1219} \right\}$	$\begin{cases} 1193 \\ 1193 \end{cases}$	$ \left\{ \begin{array}{c} 1219 \\ 1219 \end{array} \right\} $	${1216} \atop {1246}$	-2	0	+1	

It appears that in no case can the carbon atoms produce an effect much greater than the experimental errors in the determination of the intensities. In the triangular interstices the changes would be too small to detect. With the tetrahedral and octahedral interstices the effect is greater, the F_{hkl}^2 factors being modified by 2%. Further,

the tetrahedral positions are distinguished from the octahedral by the fact that some lines are uninfluenced by the carbon atoms and also that lines 4, 12 and 20 are altered in opposite directions in the two cases. For these reflections, therefore, the intensity difference between the two positions is increased to 4%. This is a difference which might be detected by careful photometric work. Thus, while one cannot expect to measure accurately such small changes, it might be possible from a number of determinations to detect the general trend of the changes produced by the carbon atoms, and so to distinguish between the three possible positions.

Experimental Details.

The experimental work required the accurate determination of the intensities of the lines of X-ray powder photographs of austenite. The austenite consisted of a manganese steel made from pure materials in an induction furnace, using a hydrogen atmosphere which was pumped out before the melt was allowed to solidify. The lump was homogenised in vacuo for 48 hr. at 1050° C.; the outside layers were removed, and filings were taken, sealed off in evacuated thin-walled silica tubes, annealed at 1050° C. for 2 hr. and finally water-quenched from this temperature. X-ray photographs taken in a 19-cm. camera, (6) using powder which passed through a 120-mesh sieve, showed only austenite lines. The lump

analysed 13% of manganese and 1.43% of carbon.

Before the 13% manganese steel was used, 2% chromium, 1.7% carbon and 2% nickel, 1% chromium, 1.7% carbon steels were tried, but it was found impossible under the conditions of quenching to obtain the powders completely in the austenitic condition, although quenched small lumps can be so retained. Subsequently, at Dr. McCance's suggestion, a 2½% manganese, 1.7% carbon steel was used, but with the same result. The effect may be due to the evacuated silica tube slowing-up the quench, but after quenching from an argon atmosphere in an open boat there was still some martensite. Decarburisation during quenching might account for this latter result. Perhaps, however, it is inherently impossible to obtain complete austenite retention with fine powders of this composition. The small particle size with large free surface could allow the volume change of the martensite reaction to be more easily accommodated, and so the reaction made more possible than in the lump. This indicates a point to be taken into consideration in the application of powder methods to the investigation of states of metastability. The ordinary grain-size effect would not explain the result, since the particle size corresponds to what is considered quite a coarse grain size in steels.

Photographs were taken with Co K_a and with Mo K_a radiations which allowed up to lines 12 and 27, respectively, to be photometered. With molybdenum radiation a monochromator was used to cut out

the general radiation, and a thin aluminium sheet was put in front of the film to absorb the K emission spectrum of iron excited by the molybdenum radiation. By this means a clear background was obtained on the film, but above line 12 only lines 19 and 20 were strong enough to be photometered accurately, so there was little advantage in having the extra number of lines on the molybdenum photograph. Consequently, except for one case, cobalt radiation was used, since the exposures could be taken in shorter times, and there was the further advantage that the depression of the atomic scattering factors of iron and manganese by the absorption-edge effect (8) (loc. cit., p. 315) increased the relative influence of the carbon on the intensities of the lines. Calibration strips were put on the films by the usual rotating stepped-sector method in order to permit correction for the non-linearity in the blackening-intensity curve of the film. Such a correction was only necessary with line 3.

Special attention was paid to the photometry, which was carried out with a Cambridge microphotometer of the Dobson type. (9) Although this is not the most convenient apparatus, it was considered capable of accuracy greater than or equal to that of other forms. In principle it is a null method in which, by a photo-electric cell, the blackening on the film is matched against a standard Ilford wedge of which the blackness increases linearly along its length. Initially the results were unsatisfactory, and success was only obtained with a special wedge manufactured by Ilford's. In this the full 5 cm. available on the instrument were utilised for the density range required. Particular attention had been paid to the uniformity of the wedge in manufacture, but, as an additional safeguard, it was calibrated to allow for slight irregularities in the blackening-length curve. Intensity determinations were made on the films at every 0.1 mm. on going through a line. The readings were continued to some distance on either side of the line to determine the average background for the line. After allowance for the film correction, the wedge correction and the background, the area under the curve of intensity against distance on the film was taken as the measure of the intensity of the line.

Six films of austenite were used and, to act as checks, two of pure copper. Except in two cases, each film was photometered twice. With all but the austenite film taken with molybdenum radiation the agreement in intensity between the two separate determinations was

within 1%.

The Observed Intensities.

For any line in a powder photograph the intensity is given by:

$$I = F^2 \cdot \frac{1 + \cos^2 2\theta}{\sin^2 \theta \cos \theta} \cdot p \cdot A \cdot e^{-B \left(\frac{\sin \theta}{\lambda}\right)^2}$$

where θ is the Bragg angle for the reflection, p is the number of

co-operating planes, A is the absorption factor, B is a constant and λ is the wave-length of the radiation used. The term $e^{-B\left(\frac{\sin\theta}{\lambda}\right)^{3}}$ is the temperature factor.

Division of the observed intensities by $\frac{1+\cos^2 2\theta}{\sin^2 \theta \cos \theta}$. p.A gives

 $F^2 \cdot e^{-B\left(\frac{\sin\theta}{\lambda}\right)^2}$. If there were no carbon atoms in the austenite the value of F^2 would in every case be $16f_{F^2}^2$. The value of f varies with the Bragg angle in a known manner, $^{(5)}$ so that $16f_{\text{Fe}}^2$ can be calculated for every reflection. This is the value $F_{\gamma, \text{Fe}}^2$ in Table I. Division of each

observed $F^2e^{-B\left(\frac{\sin\theta}{\lambda}\right)^2}$ by $F^2_{\gamma \, \mathrm{Fe}}$ would give factors in which the only variable was $e^{-B\left(\frac{\sin\theta}{\lambda}\right)^3}$. Consequently, plotting the logarithm of the result for the various lines against $\sin^2\theta$ would give a straight line. In the presence of carbon atoms, however, the F^2 values are altered from $\hat{F}_{\nu\text{-Fe}}^2$ by the small amounts shown in Table I. Thus, the observed points should be displaced from the straight line by amounts depending on the correct carbon location.

The procedure was, therefore, to divide the observed intensities

by $\frac{1+\cos^2 2\theta}{\sin^2 \theta \, \cos \, \theta} \cdot p$. A. $F_{\gamma \text{-Fe}}^2$ and to plot the logarithm of the result against $\sin^2 \theta$. The value of A was obtained by the method of Bradley. The values of F_{γ, F_0}^2 given in Table I. were not used but the slightly different results obtained after allowing for the presence of the 13% of manganese and, in the case of cobalt radiation, for the effect of the absorption edge on the f values of iron and manganese. The magnitude of the absorption-edge effect was calculated by Hönl's method. (8) The observed intensities were in arbitrary units, and were divided by a constant so that in every case the final logarithm values were about unity.

Discussion of the Experimental Results.

The deviations from the straight-line plot for the various films are collected in Tables II. and III., and the average deviations are plotted in Fig. 1. The theoretical changes in F^2 due to placing the carbon atoms in various positions are given in Table I. With cobalt radiation the 2% changes due to the carbon are increased to 2.7%, which for the logarithm values corresponds to a 1.2% deviation from the final straight-line plot.

On account of the experimental errors, great significance cannot be attached to the exact values of the deviations. However, they do seem to establish that for the odd order lines the structure amplitudes are smaller than for the even ones. This is the requirement for carbon atoms in the octahedral interstices, but the deviations shown in Table II. are rather larger than the theoretical.

Table II.—Percentage Deviations from a Straight-line Plot for Austenite, showing the Influence of Carbon as Observed from X-Ray Powder Photographs.

Film No.		Line.							
FIRM NO.		3,	4.	8.	11.	12.	19.	20.	
2023b .		-1.5	+1.3	-0.5	-3.2	+2.5	-1.8	+1.8	
1792a .		-1.8	+2.0	+2.6	-1.6	+1.4			
1793a .		-1.2	+1.0	+3.8	-1.8	+1.1		•••	
1793b .		-1.8	+1.9	+3.4	-1.9	0.0	•••		
1723a .		-1.5	+1.2	+3.2	-0.8	+0.6	•••		
1723b .		-3.5	+3.9	+3.4	-4.2	+1.2			
Average		-1.9	+1.9	+2.8	-2.2	+1.1	-1.8	+1.8	

Table III.—Percentage Deviations from a Straight-line Plot for Copper, showing the Order of the Experimental Error.

Film N	To	Line.						
Filler	10.	3.	4.	8.	11.	12.		
2242a . 2242b . Average	:	-0·6 -0·1 -0·4	$+0.4 \\ 0.0 \\ +0.2$	$^{+1.6}_{+0.1}_{+0.8}$	$+0.2 \\ +1.4 \\ +0.8$	$ \begin{array}{r} -0.3 \\ -1.8 \\ -1.0 \end{array} $		

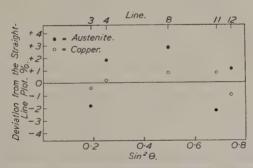


Fig. 1.—The Average Deviations from the Straight-line Plot for Austenite and Copper.

In view of the small intensity changes it is of importance to consider if the observed results can be explained by effects other than the influence of the carbon atoms. It has already been seen that the reproducibility of the measurements by the photometer is as satisfactory as can be expected, and the influence of its inaccuracies and of the irregularities of development, &c., are reduced

by taking the average of six films. Irregular inaccuracies in the values taken for the absorption factors and for the atomic scattering factors would affect the result. But, though the calculation of both these factors includes a graphical interpolation, this can be done with enough accuracy to ensure that any irregular variations would not give rise to significant deviations from the straight-line plot. The absolute values of the factors cannot be guaranteed, but any errors in them could not do more than cause the straight-line plot to be slightly curved. The photographs of copper act as a check on this, as well as on the accuracy of the measurements of intensity. Copper gives lines in very nearly the same positions as austenite, and the intensities should, of course, show no deviations from the straight-line plot, except those due to experimental error. The results for copper are recorded in Table III., and it will be observed that the deviations are mainly small, only three out of the ten being at all appreciable. It is possible to fit a slightly curved line to the copper results, and such a curvature might possibly explain the fact that the deviations for austenite were rather larger than was expected, but the curvature is not large and the points lie on a straight line within the experimental error.

Extinction (8) (loc. cit., p. 415) could not produce irregular varia-

tions.

From these considerations it is to be concluded that the observed deviations of the austenite intensities are significant. There still remains, however, the possibility that the deviations are caused by the presence of impurities. Only those impurities which give lines overlapping the austenite lines are of importance. No extra lines are visible on the X-ray photographs, and it is unlikely that an impurity which gives no extra lines detectable by eye could affect the photometer results, unless the pattern of the impurity involved strong lines exactly overlapping the austenite lines and only weak ones elsewhere. The only possible contaminations to any appreciable extent would be a-iron, martensite and FeO introduced during the preparation of the powders. For these the above condition is not true. a-Iron could not interfere, and martensite would augment line 3, contrary to the observed effect. FeO would produce lines near enough to the austenite lines 3 and 8 to show on the photometric record, but there was no trace of any such lines. The presence of Fe₃O₄ is unlikely, because the powders were annealed at 1050° C. In any case, the strong lines of the Fe₃O₄ pattern are not in positions to interfere with the austenite lines. The only lines which could do so are much weaker, and, since the strong lines are not present in sufficient strength to be detected, the weak ones cannot be appreciable. Oxygen could not be present interstitially in solution to a large enough extent to have any effect. (11) The pick-up of inclusions from the crucible is a possibility, but micro-examination showed the alloy to be clean. The pattern of the furnace material is such that the possibility of interference from this source can be dismissed by reasoning similar to that for Fe₃O₄. Even if present, it could not produce the observed trend, because lines 3 and 12 would be augmented. Thus the observed regular changes cannot be explained

by impurities.

Another question to be considered is whether ordering of the manganese atoms in special positions could have any effect. It can readily be shown that this could not be so. The lattice points are at 000, $0\frac{1}{2}$, $\frac{1}{2}0\frac{1}{2}$ and $\frac{1}{2}$. Suppose the distribution of the iron and manganese atoms amongst these positions is so complex that each point has a different scattering factor, say, f_a , f_b , f_c and f_d . Then:

$$F = f_a \cos 0 + f_b \cos 2\pi \left(\frac{k}{2} + \frac{l}{2}\right) + f_c \cos 2\pi \left(\frac{h}{2} + \frac{l}{2}\right) + f_d \cos 2\pi \left(\frac{h}{2} + \frac{k}{2}\right).$$

For a face-centred cube h, k and l are either all even or all odd. Consequently for every reflection:

$$F = f_a + f_b + f_c + f_d.$$

That is to say that, no matter how the metal atoms are distributed amongst the various lattice points, the contribution to each line is

the same, and no irregular variations can result.

So far only the possibility of carbon atoms being at the centres of the three spaces has been considered. The valency forces may be such that the carbon atoms are displaced from the centres of the interstices. However, no system based on the displacement from the centres of the tetrahedral or the triangular interstices could produce intensity results at all corresponding to the observed effects. It can also be shown that this is true for any possible system based on the displacement from the centres of the octahedral interstices. On the solution of carbon, austenite remains cubic, and this implies equal deformation along each axis. If this deformation is not produced by the insertion of a single carbon atom at the centre of the interstice, then a complex insertion will be required. possibility would be the insertion of six atoms into one interstice in the form of an octahedron with the same axes as the iron octahedron. Other possibilities would be eight atoms in cube formation with a carbon atom on the perpendicular through the centre of each face of the iron octahedron, or some still more complicated insertion. Each of these complexes implies considerable displacement of the carbon positions from the centres of the octahedral spaces. Now, the carbon atoms can only exert their maximum influence on the intensities of the lines if they are at the centres of the spaces. This follows, since the intensity depends on the summation of various terms of the type $\cos 2\pi hx$. $\cos 2\pi ky$. $\cos 2\pi lz$, where x, y, z are the co-ordinates of the carbon positions. Movement of x, y or z from the values corresponding to the centres of the spaces results in these cosine terms becoming less than unity. All the possible complex insertions require such a large displacement from the centres of the spaces that the observed intensity changes could not result. Thus the possibility of insertions other than at the centres of the octahedral spaces is eliminated. A structure with a carbon environment similar to that in cementite is one of these.

The final conclusion must be that the intensity changes are due to carbon. Although the deviations from the straight-line plot are small, they establish a trend which shows that the carbon atoms are at the centres of the octahedral interstices. Location in the other possible interstices would require the deviations to show quite different trends. The positions of the carbon atoms in austenite are, therefore, at the centres of the unit cells and at the mid-points of the edges. The structure is shown in Fig. 2. The amount of carbon

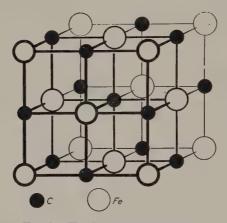


Fig. 2.—The Structure of Austenite.

present is not sufficient for each position to be occupied by a carbon atom. At the most one position in twelve is occupied. That austenite has this structure is consistent with the fact that in many interstitial structures, such as TaC, CrN, &c., (12) the small atoms occupy the centres of the octahedral spaces in the face-centred cubic metallic lattice.

Other Theories of the Structure of Austenite in Relation to the Present Results.

The state of cementite in austenite has been the subject of a large number of discussions from the thermodynamical point of view. Cesàro $^{(13)}$ concluded that the cementite must be present as molecules of carbide. Jeffery, $^{(14)}$ however, considered that there were monatomic molecules of carbon dissolved in monatomic molecules of γ -iron. Yap $^{(15)}$ first agreed with Jeffery, but finally with Cesàro. Körber and Oelsen $^{(16)}$ considered that molecules of carbide were present and Chipman $^{(17)}$ arrived at the same conclusion

for low concentrations. It would seem, however, that, as Austin (18) says, the uncertainties in the data are too great for any conclusion

to be drawn by thermodynamical reasoning.

Schwartz (19) believes there are two types of austenite. Solutions in equilibrium with graphite ave carbon has solute, those in equilibrium with cementite have the carbide in solution as such. This two-solution theory would require a doubling of the A3 line in the phase diagram, but no proof of such doubling exists. The crystallographic objections, given in the Introduction, to cementite being in solution without dissociation cannot be over-emphasised. Schwartz. in the discussion on a paper by Wells, (20) also quotes unpublished results of Nusbaum to the effect that there is a considerable difference between the lattice parameters of the austenites in equilibrium with graphite and with cementite. The difference is much greater than can be explained by the difference in carbon content, and Schwartz considers that it is to be interpreted as indicating a difference in nature between the two solutions. The lattice parameter quoted for the solution in equilibrium with cementite is in agreement with other determinations, but the solution in equilibrium with graphite gives a value near that of carbonless iron. In the absence of published details it is impossible to comment on whether there could be any experimental explanation of the results, but it is hoped to examine this point during future experiments. Such a difference, if confirmed, would be very important. The lattice parameter of the austenite used in the present work, 3.623 Å., is in agreement with the values obtained for equilibrium with cementite. Also, from electrical-resistance changes during graphitisation Schwartz infers changes in the character of the austenite when the excess cementite is replaced by graphite. The exact interpretation to be put on resistance changes is, however, always a matter of doubt. It is not felt that any convincing evidence of the existence of two austenites has been advanced.

In a theory of the solidification of cast irons Norbury (21) supposes the carbon in cementite and austenite to be present in the diamond form. Crystallographically there is no resemblance at all between the location of carbon in either of these substances and its location in diamond. In the discussion on his paper he limits the significance of his statement to meaning that the carbon atoms are in the same valency state as in diamond, in contrast to the valency state in graphite. However, even when treated from the valency point of view there is as big a difference between diamond and these substances as between diamond and graphite. In diamond each carbon atom exerts four covalencies pointing towards the corners of a tetrahedron; in cementite and austenite, however, each carbon atom is surrounded by six iron atoms at equal distances. As carbon can exert only four full valencies, it seems likely that these four bonds resonate between the six possible positions. Such a resonating bond is probably to be considered rather similar to a metallic bond.

In a rather early paper, Andrew and his co-workers (22) suggest that there are certain changes in austenite depending on the temperature to which it is heated. These, they conclude, are due to the breaking down on heating of complex molecules of carbide in solution into simpler molecules. They associate this effect with the initial temperature effect on the behaviour of steels. Such a view is not now tenable. It seems probable that their "carbide expansion" is no more than the expansion which occurs when the carbide goes into solution, and the fact that the completion of the change does follow the phase diagram can be explained as due to the sluggish solution or precipitation of the carbides. Sluggish behaviour of the carbides has since been pointed out by Hultgren, (23) Walldow (24) and Carpenter and Robertson. (25) The effect is more marked in the presence of alloying elements, particularly chromium. The carbide behaviour must be considered in heat treatment, and, in the interpretation of any variation of properties observed under conditions of continuous heating or cooling, it indicates that care must be taken to realise how far the observations are due to this sluggish carbide effect. But, from the structural point of view, their results do not indicate any changes in austenite on heating.

Acknowledgments.

The author desires to thank Professor Sir Lawrence Bragg, F.R.S., and Dr. A. J. Bradley, F.R.S., for their interest in this work. Very helpful discussion has been received from Dr. H. Lipson. The work is part of a programme supported financially by the Iron and Steel Industrial Research Council.

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CORRESPONDENCE.

Dr. S. A. Main (Messrs. Hadfields, Ltd., Sheffield) wrote: The paper seems to indicate that the atoms occupy two distinct positions, (a) at the centres of unit cells, and (b) at the mid-points of their edges, but in fact the carbon atoms appear all to be quite

similarly placed, and not in two categories.

The face-centred cubic structure being four co-equal interlacing simple cubic lattices, with the atoms of each separate lattice occupying positions at the face centres of one or other of the other three, apparently permits of four further co-equal interlacing lattices having their corners at the mid-points of each side, and simultaneously at the "body centres," of each of the original cubes. The author's location of the carbon atoms shows that they all help to form these additional lattices as far as their numbers permit.

Consideration of the mechanism by which the austenite of carbon steel breaks down to pearlite should be very helpful in ascertaining the structures of both. It is important, therefore, in trying to visualise this mechanism, to know that it is not necessary to imagine a dual process by which some carbon atoms are transferred from (a) positions and others from a different (b) position,

but only a single process for all.

The author gives well-considered reasons why the positions of the carbon atoms in the austenite of carbon steel are likely to be the same as here found, but it is a fact that the experimental material was manganese steel at ordinary temperature. It seems safer, therefore, to confine the conclusions (and the title of the paper) to that material than to apply them to austenites in general, and in the whole ranges of temperature in which these exist.

While manganese and iron have the same valencies for carbon. and manganese can substitute equally for iron in the formation of carbide from austenite, other elements, such as chromium, which enter into the formation of some austenites have a different valency. So far, therefore, as those valencies may, as directive influences. affect the arrangement of the atoms in austenite, different distribu-

tions of carbon may be looked for.

The austenite of any single carbon steel is itself variable in composition according to temperature or conditions of cooling. Does not the spontaneity with which it breaks down into pearlite under suitable conditions (slow cooling) suggest that in the eutectoid austenite, at any rate, the carbon atoms are more favourably placed for that transformation than if they had first to be marshalled or sought after, from a random distribution, by growing crystals of cementite? I have never subscribed to the idea that carbon exists in cementitic formation in austenite. Is it not possible, nevertheless, that it takes up some other orderly formation from which each atom can readily associate itself with three iron atoms when the breakdown occurs?

In the reverse process of dissolution of pearlite on heating, inspection of the author's Fig. 2 shows that with a single carbon atom newly placed in its austenitic position, six iron atoms are left with different residual affinities from their neighbours of the three lattices to which they belong and from those of the fourth lattice. In the process of further building-up, therefore, the attractive forces upon further carbon atoms not yet settled in place would be selective, and tend to group them into a separate pattern.

A further consideration is that the temperature of the A₁ point is so precise that it is difficult to believe that this transformation

could result from a haphazard arrangement of atoms.

These considerations do not apply to the same extent to austenite when it becomes diluted or concentrated by absorption of ferrite or cementite, in hypo-eutectoid or hypereutectoid steels, respectively, as the temperature is increased above A_1 . It may well be that in these circumstances there is more freedom for the random

distribution of carbon suggested by the author.

What happens at A₁ may, however, be very different in alloy steels and in carbon steel. The stratified structure of pearlite is lost with any considerable degree of alloying, so that if there is anything in the idea of favourable placing of the carbon in the austenite, those favourable formations would differ in character with the composition of the steel. The greater stability and lower temperature of transformation of some alloyed austenites—e.g., manganese steel—as compared with that of carbon steel might perhaps be explained by the affinities of the alloying elements for carbon being stronger than that of iron, but it might not be so.

These various questions will be considerably elucidated when the technique is available so that an investigation similar to that successfully conducted by the author can be made on other austenites, including carbon steel, in their stable conditions at high temperature. Doubtless, however, as things are, the investigation was

difficult enough as carried out in the cold.

AUTHOR'S REPLY.

The Author, in reply, wrote: Dr. Main's discussion raises a

number of interesting points.

I regret if any misunderstanding arises from describing the carbon positions as the centre of the unit cell and the mid-points of the edges. Crystallographically these positions are, of course, equivalent, but there is no one description which will cover them both.

Dr. Main suggests that it is difficult to explain the ease of formation of pearlite from eutectoid austenite without supposing that, as the austenite cools and the eutectoid temperature is approached, the carbon atoms take up positions which facilitate cementite formation. The evidence in the paper does not preclude the possibility of the structure of austenite changing with temperature, but it must be emphatically stated that there is no absolute necessity for any ordering of the carbon atoms, such as Dr. Main suggests. A similar point was raised in a discussion of this work at a meeting of the Structure of Alloys Research Panel, and, on a previous occasion, Dr. Main discussed a closely related question in connection with the structure of cementite. It is proposed, therefore, to deal with this matter rather fully.

The equilibrium state of any system is that state, from amongst the various possible ones, which has the lowest free energy.² The free-energy curves for ferrite, austenite and cementite have not been definitely established, but the general form that they must take can be recognised. This is shown in Fig. A for temperatures below,

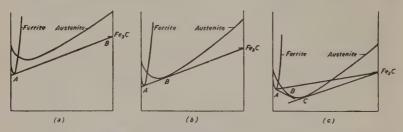


Fig. A.—Free-Energy Curves for the Iron-Carbon System, (a) below, (b) at, (c) above the eutectoid temperature.

at, and above the eutectoid temperature. There is a variation in free energy with concentration and temperature.

Below the eutectoid temperature, Fig. A(a), the lowest free energy, up to a concentration A, is represented by the ferrite curve. The carbon, therefore, is all in solution in α -iron. Beyond A, however, the lowest free energy is on the line AB, the tangent from the free energy of cementite to the ferrite curve. This means that here the stable system is a mixture of ferrite and cementite. The austenite free-energy value is always higher than the value given by these states; austenite, therefore, it is not stable at this temperature.

At the eutectoid temperature, Fig. A (b), the tangent from the cementite value to the ferrite curve is also tangential to the austenite curve. Again up to the composition A there is solubility in α -iron. At higher carbon concentrations the lowest free-energy state is

¹ H. Lipson and N. J. Petch, Journal of The Iron and Steel Institute, 1940, No. II., p. 95P.

² H. Lipson and A. J. C. Wilson, Journal of The Iron and Steel Institute, 1940, No. II., p. 107P.

represented by the common tangent. Under these conditions ferrite of composition A, austenite of composition B and cementite

are in equilibrium.

Above the eutectoid temperature, Fig. A(c), there is some solubility in ferrite. Beyond A the lowest free energy is represented by the tangent AB, so the system splits into ferrite of composition A and austenite of composition B. Between B and C the lowest free energy is given by the austenite curve, hence austenite exists as a single phase. Beyond C hypereutectoid cementite appears. A mixture of ferrite and cementite is not stable at this temperature, simply because it always represents a free-energy value higher than

that represented by the above stable conditions.

The breakdown of eutectoid austenite below a certain temperature is solely due to the fact that the relative movements of the freeenergy curves, brought about by the change in temperature, result in a ferrite-cementite mixture being a lower free-energy state than single-phase austenite. The change on cooling is controlled by the free-energy line for ferrite-cementite mixtures, the tangent from cementite to the ferrite curve first cutting, then becoming tangential to and finally, below the eutectoid temperature, becoming lower than the austenite free-energy curve. There is absolutely no necessity for any pre-knowledge on the part of the austenite, when a fraction of a degree above the eutectoid temperature, that on cooling it will have to break down, because some other state becomes of lower free energy. There is no reason why there should be any preparation for this action, just as there is no reason why there should be any preparation by pure γ -iron for its breakdown to α -iron. There is no reason why the concentration of the carbon atoms should not take place at the temperature of the change. After all, the reaction is not particularly fast.

Another point is that it is hard to see how any possible arrangement of the atoms can prepare for cementite formation. Mere association of the carbon atoms with three iron atoms is no such preparation. The formation of cementite requires a certain association of the iron atoms with each other and of each carbon atom

with six iron atoms arranged on a prism.

Dr. Main remarks on the use of an alloyed austenite. A plain iron-carbon austenite might have been used and photographed in a high-temperature camera. The photometric accuracy required was, however, absolutely on the limit obtainable with the best films. On account of the weakening of the lines, due to thermal agitation of the atoms, high-temperature photographs would have been unsatisfactory.

It appears to me improbable that the use of an alloying element in any way invalidates the drawing of a general conclusion from the results. Dr. Main's argument is that between the metal and the carbon there is a directional valency which controls the carbon location. In an alloyed austenite the carbon atoms may be directed into positions different from those that they occupy in plain austenite. The valency ideas expressed here are, however, quite wrong. It is wrong to make any valency deductions from formulæ such as $\rm Mn_3C$, $\rm Fe_3C$ or $\rm Cr_3C_2$. Actually in all these cases the carbon atoms are surrounded by six metal atoms at the corners of a prism. In austenite, and in cementite and similar carbides, there is no valency in the ordinary sense of electrovalency or covalency. The carbon atoms are joined to the metal by an undirectional bond of the metallic type. Alloying of austenite may introduce a tendency for the carbon atoms to occupy interstices adjacent to or distant from the foreign atoms. It will not, however, introduce directional forces, of the type suggested by Dr. Main, which might make the carbon atoms change the type of interstice that they occupy.

The controlling factor in the structure of the austenite examined seems to be simply that the atoms should be packed together as closely as possible. Thus the carbon atoms go into the octahedral interstices, because they are the largest available. The octahedral interstices will remain the largest independent of the presence of alloying atoms amongst the metallic atoms. It is felt, therefore, that the structural conclusions drawn from the austenite used can

be applied to austenites in general.

ON THE CARBIDE AND NITRIDE PARTICLES IN TITANIUM STEELS.*

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(Figs. 1 and 2 = Plate XX.)

SYNOPSIS.

A microscopic examination has been made of the structures of titanium steels containing from 0·1 to $1\cdot0\%$ of carbon and from 0 to $6\cdot0\%$ of titanium. Special attention was paid to the nature of the impurity constituents which are usually referred to as particles of titanium nitride. These were shown to consist of a whole series of particles ranging from yellow —— orange —— brown to grey, the grey particles being almost indistinguishable from those of titanium carbide, TiC. The general effect of increasing carbon content was to change the predominant colour from yellow to grey, but the particles in any one steel were very variable, and duplex or rimmed particles were often observed with yellow or orange interiors and brown or grey rims.

Residues were extracted from the steels by electrolytic attack in hydrochloric acid, and were submitted to chemical analysis and X-ray examination. The chemical tests showed that the yellow, orange and brown particles were attacked by chlorine at 300° C. with the liberation of free carbon and formation of volatile titanium triride, whereas titanium carbide is unattacked and titanium nitride is attacked with the formation of volatile titanium chloride. The analyses suggested that in the orange and brown crystals some of

the nitrogen of titanium nitride was replaced by carbon.

The X-ray investigation of the residues showed that the yellow, orange and brown crystals gave rise to diffuse diffraction lines corresponding to face-centred cubic structures with lattice spacings between those of TiC and TiN. The diffuseness of the lines varied greatly in different residues. The microscopic, analytical and X-ray results all agree with the hypothesis that a continuous series of solid solutions exists between TiC and TiN, and that a given steel may contain certain particles of widely different compositions.

I.—Introduction.

It is well known that titanium steels usually contain not only the constituents of the Fe-Ti-C system but also small particles of variable colour, which are due to the presence of nitrogen. Great uncertainty has existed as to the nature of these particles, which have been described by different investigators as "nitride," "cyanide" and "cyano-nitride." The object of the present work was to investigate the nature of these particles and to show the relations existing between titanium carbide, TiC, and titanium nitride, TiN.

^{*} Received November 19, 1941.

For this purpose a series of titanium steels of commercial purity, containing from 0 to 6% of titanium and from 0·1 to 1·0% of carbon, was made available by the Research Department, Woolwich. The steels were prepared in a spark-gap high-frequency furnace, and the ingots were forged to $\frac{5}{8}$ in. dia. bars, which were supplied in the furnace-cooled condition. They were examined microscopically in this state, and also after annealing for 24, 24 and 6 hr. at 700°, 800° and 1000° C., respectively, followed by quenching in ice and salt. Some of the bars were then submitted to anodic attack in 2N hydrochloric acid; the resulting residues were examined by X-ray and chemical methods, and the results obtained have thrown considerable light on the carbide-nitride relations in this series of steels.

II.—MICROSCOPIC, EXAMINATION.

The steels were ground and polished by the usual methods, and were examined microscopically in the unetched condition and also after etching in alcoholic picric acid, whilst sodium picrate was used to distinguish between cementite and other constituents. The preliminary examination of the furnace-cooled alloys showed that the constituents could be divided into three main classes:

(a) The constituents of the pure Fe-Ti-C system.

(b) Small, uniformly distributed particles, the colours of which are described below. For convenience, these may be referred to as the uniformly distributed impurity particles.

(c) Dense clusters of the impurity particles, often elongated in the direction of working of the bars. These will be referred to as impurity clusters. One of these clusters is illustrated in Fig. 1, from which it will be seen that the individual particles of the clusters are very small. The size of the clusters as a whole varied greatly, and some alloys contained streaks, several millimetres in length, consisting of a mass of densely packed impurity particles. In general, the higher the titanium and carbon contents of the steels, the greater was the tendency to form the impurity clusters, but the results were very variable, and different parts of the same bar might show quite different numbers of impurity clusters.

(d) Occasionally relatively large impurity particles were noted, and one of these is shown in Fig. 2, but this kind of

particle was exceptional.

(e) Patches of slag and unsound material.

The preliminary examination showed clearly that a proportion of the titanium was present in the form of impurity particles or clusters, and that this proportion was variable, and apparently quite uncontrolled. For this reason it was not possible to construct accurate equilibrium diagrams, since, as will be appreciated from Section IV., it is not always possible to determine the titanium present in the impurity particles and clusters, as distinct from that in the steel as



Fig. 1.—A Typical "TiN" Cluster. × 800.

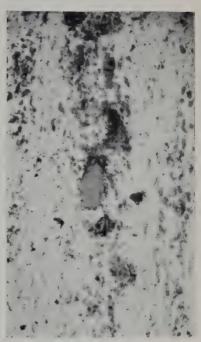


Fig. 2.—A Large "TiN" Particle. × 800.



a whole. Fig. 3 indicates the structures found in (a) the furnace-cooled alloys, and in those quenched from (b) 700°, (c) 800° and (d) 1000° C., respectively. These are based on the total titanium and carbon contents of the steels, and refer only to the constituents of the Fe-Ti-C system. It must be emphasised that the diagrams are very approximate, since in many cases a considerable proportion of the titanium, as well as some of the carbon, is present in the impurity

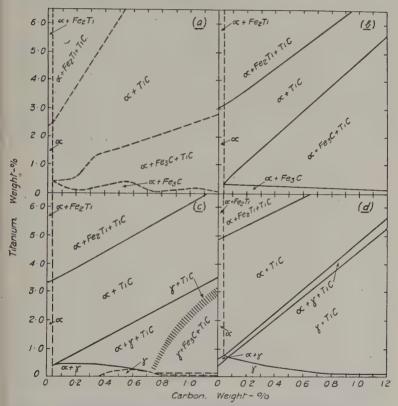


Fig. 3.—Isothermal Sections on a small scale of the alloys (a) as furnace-cooled, and as quenched from (b) 700° C., (c) 800° C. and (d) 1000° C.

particles and clusters. The annealing conditions were such that equilibrium was probably nearly attained, but the uncertain composition prevents the diagrams from being more than a description of the structures observed for this particular batch of steels.

These diagrams are in reasonable agreement with the equilibrium diagrams given by Tofaute and Büttinghaus. (1) The present diagrams are based on the examination of 48 alloys, but they are not to be re-

garded as replacing the earlier equilibrium diagrams. The authors had not intended to publish these diagrams, but it was suggested that readers unfamiliar with the German work would not know the structures of the steels referred to. The present diagrams merely connect the structures of the particular batch of steels examined with the compositions of the steels as a whole. In many cases, however, the proportion of titanium in the impurity patches is considerable, and is so clearly an uncontrolled variable that the structures of another batch of steels of the same composition but prepared under different conditions might be quite different.

Cementite, ferrite, pearlite, martensite and troostite showed their usual etching characteristics, whilst the iron-titanium phase Fe₂Ti appeared as a light-etching constituent. Titanium-carbide particles appeared blue-grey in unetched sections, and were darkened to a

grey-brown when etched in picric acid.

A systematic examination of the impurity particles showed that increasing carbon content produced a regular series of changing colours of these particles in the direction yellow -> orange -> brown → grey. Further, duplex or rimmed particles frequently existed in which the centre was yellow or orange and the outside orange, brown or grey; in all cases the inside of a duplex particle was nearer to the vellow end of the above series of colours than the outside. These colour differences are shown most clearly in unetched sections. since etching with picric acid darkens the particles and diminishes the contrast between the brown and grey particles. In many of the alloys of high titanium and carbon content impurity particles and clusters of a wide range of colours would exist, but the general tendency for increasing carbon content to change the predominant colour from yellow to grey was very clear, and increasing titanium content produced the same effect although to a lesser degree.* the steels of high titanium and carbon contents many of the particles of the impurity clusters were either entirely grey or had grey rims which were almost indistinguishable from the titanium-carbide particles present as a genuine constituent of the Fe-Ti-C system. The annealing treatment at 800° C. did not appear to affect the impurity particles or clusters, but the great variation between different parts of the same bar made a detailed investigation of this point impossible.

The microscopic investigation shows clearly that a whole range of impurity particles exists, and two interpretations are suggested. Either (a) a series of solid solutions may be formed by TiN and TiC, and the duplex particles may be the result of severe coring, or (b) compounds which are essentially nitrides may solidify first and then undergo peritectic reactions with the melt to produce carbide. The work described in the succeeding Sections suggests that the

former alternative is the more probable.

^{*} Photographs of the particles are not included, since the distinction between the different types depends on colour differences alone,

III.—X-RAY INVESTIGATIONS.

(a) Titanium Nitride.

In order to obtain a standard for comparison, titanium nitride was prepared synthetically by heating commercially pure powdered titanium metal in a slow current of nitrogen. Great difficulty was experienced in obtaining a product which gave sharp X-ray diffraction lines, and the method finally adopted was to place the powder in an alumina boat inside a silica tube, and to pass a slow current of nitrogen while the tube was heated in an oxy-coal-gas flame to a temperature just below that at which the silica began to soften. this way yellowish-brown powders were obtained, and, although their X-ray diffraction lines were not of the highest quality, they gave clearly resolved doublets in the 19-cm. Debye-Scherrer camera. The films all showed the diffraction lines characteristic of the facecentred cubic (sodium chloride) structure, and the lattice spacings were determined by standard methods. The results are shown in Table I., which also gives the ratio of titanium to nitrogen in the

Table I.—Titanium Nitride Standard. Ratio of Titanium to Nitrogen, and Lattice Spacing.

Time of Annealing. Hr.	Ratio of Titani	Lattice Spacing	
	By Weight.	By Atoms.	Å.
1 4 65 4 1 2	1:0.279 1:0.280 1:0.288 1:0.308	1:0.955 1:0.957 1:0.985 1:1.052	$\begin{array}{c} 4.2331 \\ 4.2333 \\ 4.2329 \\ 4.2321 \end{array}$

different specimens. All these products contained from 1 to 3% of iron by weight, and attempts were therefore made to prepare the nitride from pure "titanium hydride," after removal of the hydrogen by heating in a vacuum. All samples prepared in this way gave rise to diffuse X-ray diffraction lines, even when the time of annealing in nitrogen was extended to considerably longer periods than those given in Table I. References to the literature suggest that even at 2000° C. some hydrogen is not removed from the hydride material, and it is possibly this fact which accounts for the unsatisfactory nature of the nitride material which was obtained.

The results in Table I. show that the lattice spacing diminishes as the proportion of nitrogen increases, and there is an approximately linear relation between the lattice spacing and the ratio of titanium to nitrogen by atoms. These figures may be compared with the value a = 4.235 Å. given by Brager, (2) according to whom products with less titanium than the equiatomic ratio are not simple substitutional solid solutions, but are the result of titanium dropping

out of the lattice and leaving empty spaces.

(b) Titanium Carbide.

Previous work has indicated that titanium carbide crystallises with the sodium chloride structure, so that the titanium atoms alone may be regarded as occupying a face-centred cubic lattice. The authors have extracted the carbide electrolytically from a steel containing 5.80% of titanium and 0.58% of carbon, and the lattice spacing was determined accurately as $a=4.3251\pm0.0002$ Å. at 25° Ç. The work is referred to in sub-section (d) below and the above value of the lattice spacing may be compared with the values of 4.315 Å. and 4.325 Å. given by Hofmann and Schrader (3) for synthetic titanium carbide and for a titanium carbide residue from a cast iron.

The authors think that the value obtained in the present work refers to what is essentially pure TiC for the following reasons: (1) The X-ray lines were very sharp. (2) The films from the other residues referred to below showed the same sharp lines, and gave the same lattice spacings in spite of the fact that the compositions of the residues were different. (3) The analysis referred to in Section IV. (e) below showed that the portion of the residue which was non-volatile in chlorine contained titanium and combined carbon in the equiatomic ratio. (4) The analytical results show that there is little or no contamination by impurities or by oxygen.

notic of no contamination by impurities of by oxygen.

(c) Yellow Crystals in a Steel containing 2.28% of Titanium and 0.05% of Carbon.

Microscopic investigation revealed that in the steel containing 2.28% of titanium and 0.05% of carbon the impurity particles were nearly all of a yellow colour, and this steel was therefore submitted to electrolytic attack in the hope that the residue would give rise to a simple X-ray diffraction pattern. Actually the film obtained was very complicated, and later work (see sub-section (d) below) suggested that many of the extra lines were due to inclusions of slag or similar material. The film contained all the lines to be expected for TiN, and these were of a rather fuzzy nature, suggesting that the particles were not all of the same composition.* The mean lattice spacing could, however, be measured fairly accurately, and the value obtained was a = 4.240 - 4.241 Å. at 23° Č. This value is distinctly larger than that of the synthetic TiN, and the difference is greater than the uncertainty due to the rather diffuse nature of the lines on the film, so that this work establishes the fact that the yellow crystals have a larger lattice spacing than the synthetic material.

(d) Yellow, Orange and Brown Crystals in a Steel containing 5.8% of Titanium and 0.58% of Carbon.

Microscopic examination showed that in the steel containing 5.8% of titanium and 0.58% of carbon both the uniformly distributed

* The alternative explanation that the diffuseness is due to the very small particle size does not appear probable, because the steel undoubtedly contained many yellow crystals of reasonable size, and if these had been of uniform composition one would have expected a sharp line on a fuzzy background.

impurity particles and the particles in the impurity clusters were yellow, orange or orange-brown, and that duplex particles existed with yellow centres and orange or brown rims. The steel is in the $(\alpha + \text{TiC})$ region, and residues were extracted electrolytically in the hope of throwing light on the relations between the impurity particles and the carbide. The results were of considerable interest, but are complicated by the fact that different results were obtained from different parts of the bar.

The bar was first submitted to electrolytic attack until a layer about $\frac{1}{16}$ in. had been dissolved. The resulting residue, which may be called residue No. 1, was too small for chemical analysis, but was sufficient for X-ray examination, and successful photographs were taken in both the 19-cm. and the 9-cm. Debye-Scherrer cameras. The films showed lines due to two face-centred cubic structures. One set of lines was sharp, and was identified as belonging to titanium carbide of lattice spacing $a=4.3251\pm0.0002$ Å at 25° C.; it is this product which is referred to in sub-section (b) above. The other set of lines was very diffuse, and corresponded with a face-centred cubic structure with lattice spacing approximately a=4.29 Å; although these lines were diffuse, they were distinct from the lines due to titanium carbide.

The bar was then submitted to further electrolytic attack until a layer about \(\frac{1}{4} \) in. thick had been dissolved. The resulting residue may be called residue No. 2, and was sufficient for a complete chemical analysis, which is described in Section IV. The X-ray film from residue No. 2 contained a large number of extra lines, which, as shown below, were due to inclusions of slag. The film showed the lines due to titanium carbide and also very diffuse lines of a second face-centred cubic structure. In contrast to the lines on the film from residue No. 1, the diffuse lines from residue No. 2 were not separated from the lines due to the titanium carbide, but extended right up to these, showing that a much wider range of lattice spacings was present. The diffuse lines were, however, at a distinctly lower angle than the corresponding lines on the film from the synthetic titanium nitride, thus showing that the whole of the yellow, orange and brown crystals have lattice spacings greater than that of the synthetic nitride. The lattice spacing of the titanium carbide in residue No. 2 was determined as $a = 4.3252 \pm 0.0003$ Å. at 29° C.

In view of the great difference between the films from residues Nos. 1 and 2, the bar was submitted to further electrolytic attack until the one end was reduced to a tapered point. During this process some nodules were seen to protrude from the surface of the bar, and these were removed and submitted to chemical analysis and X-ray examination; this product will be referred to as residue No. 3 nodules, and the main part of the residue as residue No. 3 (main portion). Chemical analysis showed that the nodules contained large amounts of iron and silica, and the X-ray film from the nodules contained all the extra lines which were present in the film

from residue No. 2 but not in that from residue No. 1. These extra lines may therefore be reasonably ascribed to inclusions of a slag-like nature. The film from residue No. 3 (main portion) was comparatively simple, and, like the film from residue No. 1, showed lines due to two face-centred cubic structures. One series of lines was sharp, and was due to titanium carbide, the lattice spacing of which was measured as $a=4.3247\pm0.0003$ Å. at 23° C., in fair agreement with the result from residue No. 1. The second set of lines was very much more diffuse than in the film from residue No. 1, showing that a much wider range of lattice spacings existed, all of which were less than that of titanium carbide but considerably greater than that of the synthetic nitride.

The general conclusions to be drawn from a study of these films

may be summarised as follows:

(1) All the films show the sharp lines due to TiC, and these may reasonably be ascribed to the TiC which forms a genuine constituent of the alloy, as distinct from the constituents of the impurity patches.

(2) All the residues give fuzzy lines lying outside the TiC lines, indicating a second face-centred cubic structure of smaller lattice spacing. If, for abbreviation, we call this constituent "nitride," then different residues from the same bar contain the TiC and "nitride" in quite different proportions, and the fuzziness of the "nitride" lines varies greatly in different residues. In residue No. 1 the "nitride" and TiC lines are quite clearly separated, whereas in the other residues they overlap considerably but by variable amounts. The authors have not succeeded in finding any marked difference in the appearance of the yellow, orange and brown crystals at the outside and inside of other portions of this bar, so that residue No. 1 may perhaps be regarded as obtained by rather a fortunate coincidence as the result of extracting a quantity of residue too small for analysis.

(3) The residues may or may not contain additional lines which are connected with the appearance of nodules during the electrolytic attack, since the lines are present to the greatest extent in the

specimen prepared from the nodules of residue No. 3.

IV.—Analysis of the Residue Extracted from the Steel Containing 5.8% of Titanium and 0.58% of Carbon.

The residue from this steel was submitted to a detailed chemical analysis, and it will assist the understanding of the results if it is explained that titanium carbide is unattacked by chlorine at 300° C., whereas the nitride is decomposed with liberation of volatile titanium tetrachloride. The yellow, brown and orange crystals are decomposed by chlorine with the liberation of free carbon and the formation of volatile titanium tetrachloride. These reactions enable the residues to be analysed in considerable detail.

The analysis of residue No. 2 was carried out in different stages,

and the results may be summarised as follows:

(a) Approximately 0·1 g. of the residue was dissolved in sulphuric acid; a small white residue of silica remained undissolved after

repeated evaporation to dryness, and was filtered and weighed. The filtrate was then used for the determination of iron, titanium and manganese. Free carbon was determined from another portion of the residue, and the complete results may be expressed in the form:

SiO ₂		3.64%	Free c	arbon		0.16%
Fe		2.93%	Mn			Trace.
Ti		71.85%				

(b) The total carbon was determined by two separate experiments, using approximately 0.07 g. in each. The two values obtained were 8.14% and 8.06%, respectively, and the mean value may be taken as:

Total carbon = 8.10%,

and this, together with the result from (a), gives the combined carbon as:

Combined carbon = 7.94%.

- (c) The nitrogen was determined by a modified Kjeldahl method, using approximately 0·1 g. of material, and the result was:

 Total nitrogen = 13·39%.
- (d) Approximately 0.05 g. of material was submitted to chlorine treatment, and the loss in weight was 70.76%. The resulting black product was dissolved up for the determination of free carbon and titanium. The titanium content, expressed as a percentage of the original amount of residue taken, was 14.55%, so that, since the total titanium content of the residue determined in (a) was 71.85%, the amount of titanium volatile in chlorine is 71.85 14.55 = 57.3%. The free-carbon content of the black product was equivalent to 4.26% of the original weight of residue taken. This figure includes the 0.16% determined in (a), so that the carbon set free by the chlorination process is 4.26 0.16 = 4.10%. Since the total combined carbon in the original residue (determination (a) above) is 7.94%, the amount of combined carbon which is not liberated by chlorination is 7.94 4.10 = 3.84%.

(e) The result of the analyses may then be expressed as follows:

Analysis of Residue No. 2. %. Atomic Ratios. 0.06 3.64 Silica 2.930.0521Iron Titanium: 1.198 Volatile in chlorine 57.30 Non-volatile in chlorine 14.55 0.30413.39 0.955Nitrogen . 0.32Combined and not liberated by chlorine 3.84 Combined in original residue but liberated by chlorine 0.3424.100.01330.16Free in original residue . Trace Manganese 99.91

(f) The chlorination experiments show clearly that only part of the titanium is volatile in chlorine and also that the action of

chlorine on the residue is to produce free carbon. Since TiC is known to be unattacked by chlorine at the temperature of the experiment, it is reasonable to conclude that the chlorine attacks the orange and brown crystals, with the liberation of (a) free titanium, which volatilises as chloride, and (b) free carbon, which remains with the unattacked TiC.

Since none of the X-ray films from the residues contained lines due to cementite, it is unlikely that any of the iron in the residue is in the form of cementite, and in view of the high iron and silica contents of the nodular material of residue No. 3 (nodules) it seems reasonable to assume that the iron and silica existed in residue No. 3 in the form of nodular material of a slag-like nature. The proportions are not inconsistent with FeSiO₃, but the amounts are too small to permit of further investigation.

Dealing with the main constituents, it will be seen that the atomic ratios of the titanium non-volatile in chlorine and of the carbon combined but not liberated by chlorine are: Titanium 0·304; carbon 0·32. The titanium and carbon are thus in equiatomic proportions, confirming that this substance is TiC. In view of the small quantities

available for analysis, the agreement is very satisfactory.

Dealing with the remainder of the titanium, the following are the figures for the atomic ratios:

Titanium volatile in chlorine 1.198

Nitrogen . 0.955 Carbon combined in original residue but liberated by chlorine . 0.342

1.297

The ratio of titanium volatile in chlorine to nitrogen plus carbon liberated on chlorination is therefore 1.198:1.297=0.925:1. This ratio is very nearly unity, and thus suggests a replacement of nitrogen by carbon in the orange and brown crystals. It must be emphasised that this is only an average value, and that particles of a wide range of composition undoubtedly exist. It will be appreciated that the analytical results involve four distinct series of experiments, and although every care was taken to use a thoroughly shaken and well mixed residue, there is always the possibility of small errors arising from uneven composition of different portions, since both the X-ray work and the analyses of the other residues show how completely different results can be obtained from the same bar. It does not, therefore, appear justifiable to discuss whether the ratio 0.925:1 is really different from unity. It can be said, however, that there is no tendency to form titanium cyanide, Ti(CN)2, since this would require quite a different ratio. Titanium cyanonitride is sometimes described in the literature as having the formula Ti(CN)₂.3Ti₃N₂, which is equivalent to Ti₁₀C₂N₈. This implies a ratio of carbon to nitrogen atoms of 1 to 4, whereas the authors' result is 1 to 2.8, but as already stated the authors' product is undoubtedly a mixture of different particles. The X-ray films

suggest strongly that we have nothing but a Ti(C_xN_{1-x}) series of solid solutions, since, although there are extra lines on the film of residue No. 2, these are satisfactorily accounted for by the nodular material, and the film of residue No. 1 contains nothing but the lines due to the two face-centred cubic structures.

The nodules of residue No. 3 (nodules) were submitted to analysis; they were found to be free from alumina, but to contain much iron and silica. The details are not discussed here, since they throw no light on the relations between titanium carbide and nitride. analysis was also made of residue No. 3 (main portion), and the results indicated the presence of a greater proportion of iron and titanium than could be accounted for by any reasonable assumption. The analysis appeared quite satisfactory, and it could only be concluded that some of the impurity clusters contained titanium or iron-rich material which was mechanically entrapped and so protected from the electrolytic attack. These results are not therefore discussed in detail.

V.—Conclusions.

The main conclusions to be drawn from the above work may be summarised as follows:

(1) The microscopic, X-ray and analytical results are all in agreement, and suggest that the impurity particles in the titanium steels involve a series of solid solutions between titanium carbide and nitride.

(2) The general effect of increasing carbon content is to change the colour of the impurity particles in the direction yellow -> orange --> brown --> grey, and duplex particles are frequently observed. Increasing titanium content causes the same change, although to a less marked extent. The distribution of colour is, however, very variable, and different parts of the same bar may give different proportions of the various colours.

(3) The X-ray results show that the lattice spacings of the vellow and brown particles lie between those of TiC and TiN, and suggest that a wide range of compositions exists in the steel contain-

ing 5.8% of titanium and 0.58% of carbon.

(4) The chemical analysis shows that part of the residue from anodic attack in hydrochloric acid is decomposed by chlorine with the liberation of free carbon and the formation of volatile TiCl4. The numerical values suggest that replacement of nitrogen in TiN by carbon is taking place in the yellow, orange and brown particles.

Approval for publication has been granted by the Controller General of Research and Development, the Ministry of Supply.

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CORRESPONDENCE.

Dr. C. E. Ransley and Mr. H. P. Rooksby (Research Laboratories of The General Electric Co., Ltd., London) wrote: We are very interested in the results of the investigation into the nature of the titanium carbide/nitride residues. About ten years ago, when we were investigating various kinds of filament materials, we made some observations on the zirconium system which show that it is very similar. Our experiments were never satisfactorily completed and the results were not published, but a few details may be relevant here.

We obtained zirconium nitride as a dark brown powder by heating the metal in nitrogen. Filaments extruded from this material and sintered by passing current through them were pale yellow in colour. X-ray examination showed that the nitride thus prepared had a face-centred cubic lattice with $a_0 = 4.566$ Å.; a little oxide was found to be present, but the effect of this was not considered

important.

The carbide is grey in colour, and we found for the lattice

parameter $a_0 = 4.680 \text{ A}$.

By heating these carbide and nitride filaments in various atmospheres striking colour changes were observed, and corresponding to these changes a continuous change in the X-ray pattern occurred. For example, a purple-coloured filament resulted from heating a nitride specimen in hydrogen saturated with paraffin, and the lattice parameter shifted appreciably towards the figure for carbide. Blue, red and even greenish filaments were also prepared by modifying the heat treatment and the atmospheric conditions, although in many instances we failed to achieve a homogeneous condition throughout the diameter of the filaments.

There was no doubt, however, that the nitride and carbide of zirconium formed a continuous series of solid solutions, with the lattice parameters changing systematically with composition. There is thus a very close analogy with the titanium carbide/nitride system; not only is there mixed crystal formation but also there appear to be similar colour changes with change in the ratio of

carbide to nitride.

Dr. A. H. Jay (The United Steel Companies, Ltd., Stocksbridge, near Sheffield) wrote: I have examined by means of X-ray analysis titanium compounds separated from steels by the alcoholic iodine method. This was part of a programme which will be published later as an Oxygen Sub-Committee Report. Results up to the present have shown the following phases to be possibly present: Ferrous titanates (FeO.TiO₂, 2FeO.TiO₂), titanium carbide and titanium nitride. In no case has a phase corresponding to titanium cyano-nitride been found. The titanium carbide and nitride

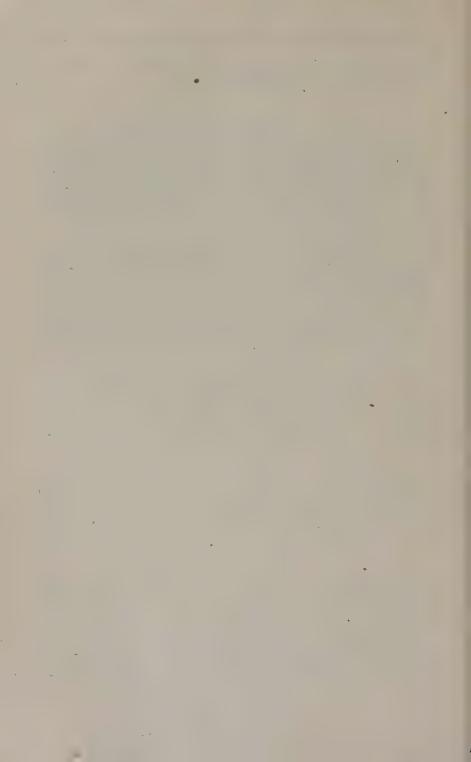
NITRIDE PARTICLES IN TITANIUM STEELS.—AUTHORS' REPLY. 141 P

patterns are clear and separate. Work on other steels is in progress to find this elusive cyano-nitride phase.

AUTHORS' REPLY.

The AUTHORS replied: We must thank Dr. Ransley aud Mr. Rooksby for their interesting communication, from which it appears that the carbide/nitride relations for zirconium and titanium show a striking similarity. It seems probable that similar relations exist for the carbides and nitrides of many of the transition elements. We are interested to note that Dr. Jay confirms the non-existence of the cyano-nitride.

This paper was presented for discussion at a Joint Meeting, organised by The Iron and Steel Institute in conjunction with the Sheffield Society of Engineers and Metallurgists, the Sheffield Metallurgical Association and the South Yorkshire Section of the Institute of Chemistry, held in the Assembly Room, Royal Victoria Station Hotel, Sheffield, on Wednesday, 24th June, 1942, at 7 P.M., under the Chairmanship of Dr. W. H. Hatfield, F.R.S. (Vice-President of The Iron and Steel Institute; President of the Sheffield Society of Engineers and Metallurgists). The discussion will be recorded in the No. II. volume of the Journal of The Iron and Steel Institute for 1942.



THE LATTICE SPACINGS AND CRYSTAL STRUCTURE OF CEMENTITE.*

BY WILLIAM HUME-ROTHERY, M.A. (Oxon.), D.Sc. (Oxon.), F.R.S., GEOFFREY VINCENT RAYNOR, M.A. (Oxon.), Ph.D. (Oxon.), and ALEXANDER TORRANCE LITTLE, B.Sc. (GLASGOW), (INORGANIC CHEMISTRY LABORATORY, UNIVERSITY MUSEUM, OXFORD).

SYNOPSIS.

Cementite was extracted by electrolytic attack from three steels of different compositions, and the lattice spacings were determined by Debye-Scherrer photographs in a 19-cm. camera. The values obtained were $a=4\cdot5155$ Å, $b=5\cdot0773$ Å, $c=6\cdot7265$ Å at 25° C., and differed from those previously given by Lipson and Petch, whose specimen had partly decomposed during annealing. No difference could be detected between the lattice spacings of the three different samples, and the analysis of one of them confirmed the composition Fe_3C . The structure is discussed, and a possible mechanism is suggested for the formation of cementite from martensite.

I.—Introduction.

THE crystal structure and lattice spacing of cementite have recently been investigated by Lipson and Petch, (1) whose material was not actually extracted from a steel, but was prepared by passing carbon monoxide over ferric oxide at 550° C. The substance prepared in this way was used for structure analysis, but did not give sufficiently sharp lines for the accurate determination of lattice spacings, and these were determined after annealing the powder for 17 hr. at 600° C. This annealing treatment resulted in the partial decomposition of the cementite, mostly into ferrite, but sometimes into another structure, which was probably Fe₂C. In view of the rather unusual method of preparation of the cementite used by Lipson and Petch, it appeared desirable to examine the cementite which is actually contained in steels, and the present paper describes the result of this investigation, which has shown that the cementite examined by Lipson and Petch had lattice spacings different from the constituent in steels.

The cementite examined in the present work was extracted from the steels, the compositions of which are given below, by electrolytic attack in hydrochloric acid, and was washed with distilled water, alcohol and ether. The resulting product did not give very satisfactory photographs, and it was therefore sieved in order to remove the very fine-grained material. The residue was gently

^{*} Received November 7, 1941.

broken up with a pin-head and again sieved, and the coarser portion used for the preparation of the X-ray specimen, which was mounted on a hair in the usual way with Canada balsam. The X-ray powder photographs were taken in a 19-cm. Debye-Scherrer camera, using filtered cobalt radiation. The steels examined were supplied by the Research Department, Woolwich, and had the following nominal compositions:

These steels were all of commercial purity, and contained approximately 0.5% of manganese, and 0.1% of silicon, &c. The products extracted from steels Nos. 1 and 2 gave X-ray films with well-resolved sharp α -doublets, and, in spite of a rather dark general background, were excellent for visual measurement. The product from steel No. 3 gave a less satisfactory film, and is referred to only briefly below.

II.—ANALYTICAL RESULTS.

The electrolytic product from steel No. 1 was examined analytically by both qualitative and quantitative methods. Only 0·3 g. was available for analysis, and the composition was found to be:

Iron, 92·95%. Total carbon, 7·05%. Free carbon, 0·53%. Combined carbon = $7\cdot05 - 0\cdot53 = 6\cdot52\%$.

The cementite thus contains 92.95 parts of iron to 6.52 parts of carbon, or 6.58% of carbon. With the small quantities used, the accuracy of the carbon determination is estimated to be of the order \pm 0.05%, so that the figure for combined carbon is accurate to \pm 0.1%, since two determinations are involved. In view of the small amount available, the agreement with the formula Fe₃C (6.68% carbon) is satisfactory, and the product examined may be regarded as possessing the usually accepted composition. Two independent tests failed to give any indication of the presence of manganese, and from the above figures it will be seen that, if the error in the carbon determination is 0.05%, the manganese content cannot in any case exceed 0.05%.

III.—LATTICE-SPACING MEASUREMENTS.

With cobalt radiation, the outermost lines which are of importance may be summarised as follows: The outermost line consists of an overlap of the strong (432) and (145) lines, and the details of this overlap are considered later. The next two lines are the (136) and (251) lines, of which the $(136)\alpha_1$ and $(251)\alpha_2$ lines overlap, and the nature of this overlap is considered later. The $(136)\alpha_2$ and $(251)\alpha_1$ lines are quite clear of the overlap, and can be used for accurate measurement.

The next suitable line is the (334), of which the α_1 component is overlapped by the $(423)\alpha_2$ line and is useless. The $(334)\alpha_2$ line lies in between the α_1 and α_2 lines of the (226) reflection, but this is so faint a line that in the 19-cm. camera the $(334)\alpha_2$ line can be used to a reasonable degree of accuracy. The next satisfactory line is the (107) line, of which the α_1 component is clear and satisfactory, although the α_2 component is overlapped by the $(430)\alpha_1$ line. The next two strong lines are the (152) and (235) lines, both of which are clear and satisfactory.

For the determination of the axial ratios we have therefore the

following lines:

These lines range from 77.79° to 69.29° , and their combination is very fortunate, since the high values of k and l enable the one axial ratio to be determined accurately. The structure of cementite is orthorhombic, and the equation for the b side of the unit cell may be written in the form:

$$b = d\sqrt{\frac{h^2}{N^2} + k^2 + \frac{l^2}{M^2}}$$

where d is the interplanar spacing, and N = a/b, and M = c/b.

If, therefore, the axial ratios are chosen correctly, the values of b calculated for the different lines from this expression should lie on one straight line when plotted against $\cos^2\theta$, as in the method of Bradley and Jay. Using the axial ratios given by Lipson and Petch, the different points did not lie on one straight line, but, on adjusting the axial ratios to the values given in Table I., a satis-

Table I.—Lattice Constants of Cementite.

			Present Work.	Lipson and Petch.
a	•		4.5155	4.5144
Ъ			5.0773	5.0787
c			6.7265	6.7297
a/b			0.88934	0.888888
c/b	-		1.32481	1.32508

factory straight line was obtained, and the high values of k and l in the (136), (251) and (107) lines mean that the axial ratio M=c/b is established to a high degree of accuracy. It was also noticed that the revised axial ratios given in Table I. required an almost exact overlap of the $(136)\alpha_1$ and the $(251)\alpha_2$ lines. Calculation shows that the peaks of these lines should differ by about 0.08 mm. on the film of the 19-cm. camera. This overlap line was then examined in a Hilger photo-electric microphotometer and was found to 1942—i

consist of a sharp, well-defined line with a horizontal top, of width between 0.1 and 0.2 mm. No great significance attaches to the actual value, since the films were exposed for visual examination, and were thus over-exposed for the best results from the photometer. The photometer record showed clearly that there was an almost but not quite exact overlap of the $(136)\alpha_1$, and $(251)\alpha_2$ lines, whereas the axial ratios of Lipson and Petch would require a separation about ten times as great. This furnishes additional proof of the correctness of the choice of the axial ratio M = c/b, but, on account of the low values of h in the (136) and (251) lines, it is not a sensitive test for the accuracy of the second axial ratio, N = a/b. It was, however, found that the axial ratios given in Table I. were such that the values of $\sin \theta$ for the (432) and (145) reflections were identical to within 1 part in 50,000. The highangle doublet on the film was then examined visually and by means of the photometer, and was found to have the characteristics of a single reflection.* This confirms that the second axial ratio, N=a/b, has been chosen correctly, since the values of h are very different in the two lines, and the point for the single (432,145) line lay on a satisfactory Bradley-Jay cos26 straight line through the remaining points.

We have thus two independent checks that the correct axial ratios were deduced by the adjustment to obtain a single straight-line Bradley-Jay $\cos^2\theta$ plot. Having established the axial ratio in this way, the b lattice spacing was readily determined by the usual $\cos^2\theta$ method; the outermost (432,145) line lies at approxi-

mately 80.69°, and has a satisfactorily high angle.

This work was carried out on the cementite extracted from steel No. 1, and identical results were obtained from steel No. 2. As explained previously, the film of the cementite from steel No. 3 was very much less satisfactory. For four of the outermost six lines of this film, the angles of reflection agreed within 0.02° with those of the first two films, and for the remaining two lines the differences were 0.04° and 0.08°, respectively. This film was not accepted as suitable for accurate measurement, but the agreement of the angles is sufficiently close to show that no appreciable difference exists between the lattice spacing of this and the other two samples of cementite, and to confirm the present results, in contrast with those of Lipson and Petch. It may therefore be reasonably claimed that the present figures are characteristic of the cementite found in three quite different steels. Correspondence with Dr. Lipson has shown that the lattice spacings that he obtained were undoubtedly correct for the sample which he examined, and the difference between the two investigations is presumably the result of the partial decomposition during the annealing of the cementite used by Lipson and Petch. If it is

^{*} The axial ratios of Lipson and Petch require a considerable separation of the two lines.

accepted that a change in composition is accompanied by a change in lattice spacing, the present results may be taken to indicate that the cementite in these steels is of constant composition.

IV .- THE MARTENSITE-CEMENTITE TRANSFORMATION.

As pointed out by Lipson and Petch, the crystal structure of cementite appears to bear little relation to the structures of either α - or γ -iron, and any simple connection between these structures is difficult to trace. It is well known that cementite is formed from martensite at considerably lower temperatures than from austenite,

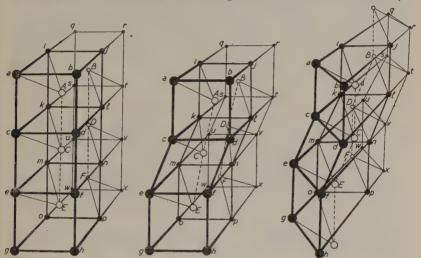


Fig. 1.—Body-Centred Fig. 2.—Shear Displace-Fig. 3.—Final Adjust-Cubic Structure (Martensite). ment of Half Length of Cube Side. ment Produces Cementite Structure.

Figs. 1 to 3.—Formation of Cementite Structure from Martensite Structure by Shear. In these diagrams only the positions of the iron atoms are shown. The atoms at the corners of the body-centred cubes are represented by full circles, the size of which diminishes as the atoms recede. The atoms at the centres of the cubes are represented by open circles, the size of which again diminishes as the atoms recede. Individual atoms are identified by means of letters.

and this fact suggests that the relative positions of the iron and carbon atoms in martensite are specially favourable for this transformation and so enable it to take place with comparatively small atomic movements at a low temperature. The following description is intended to show that the structure of cementite can in fact be derived from that of martensite by a comparatively simple shearing process, and it is tentatively suggested that this may explain the ready formation of cementite from martensite.

In austenite the carbon atoms are almost certainly placed at the centres of the unit cubes, and are thus surrounded by six iron atoms at the corners of an octahedron. If it is accepted that, after the formation of martensite, the martensite (110) plane and [111] direction are parallel to the (111) and [110] direction of the parent austenite, the most probable positions of the carbon atoms are at the centres of the square faces of the unit of the bodycentred tetragonal cell. Martensite is tetragonal, but the axial ratio is only 1.03, so that the structure is very nearly cubic. simplicity in description the structure of martensite will be drawn as that of a body-centred cube, since this enables the changes to be grasped more readily and does not invalidate the argument. Fig. 1 shows six unit cells of a body-centred cubic structure, and the carbon atoms are to be thought of as occupying the centres of square faces such as aikc, ckme, &c. In the actual tetragonal structure those faces remain square, and the structure is to be regarded as that of Fig. 1 stretched slightly in the direction ab.

If, now, a simple shear takes place in the central layer of cubes, such that the top and bottom layers are displaced relatively to each other by an amount of the order of $\frac{1}{2}a$, where a is the length of a side of the unit cube, the stage shown in Fig. 2 is reached. The displacement has taken place in the [100] direction. This structure contains several features which show similarity with the structure of cementite as regards the general atomic configuration, and may be regarded as a distorted form of the cementite structure. Comparatively minor adjustments of angles and distances enable the cementite structure to be formed, and the final structure is shown

in Fig. 3.

The essential changes in this final adjustment may be conveniently summarised as follows:

- (a) The carbon atoms take up positions which are alternately a little outside or inside the planes of faces such as aikc, ckme, &c. In the diagram, carbon atoms should be placed outside the planes aikc, emog, jrtl and nvxp, and inside the planes ckme and ltvn. This displacement of carbon atoms allows a contraction of the faces concerned, so that, for instance, the distances ai and ac contract while the face remains approximately square. It is clear that this must lead to an expansion of distances such as bj and iq, while the angle between the planes which were the vertical faces of the parent cubes is no longer a right angle, but greater. The distances such as ab also contract.
- (b) At the same time the distance of the central atoms of the sheared middle section of the structure from corners such as c and k, or n and v, increases in such a way that these atoms (e.g., C and D) lie either vertically below the central atom of the unit above or vertically above the central atom of the unit

below. Thus, atom C falls vertically below atom A, and

atom D vertically above atom F.

(c) It must also be assumed that the distances iA, aA, bC, cC, &c., also increase from a value close to that characteristic of the body-centred cube (approximately 2.48 Å. for α -iron) to the value of 2.68 Å. characteristic of cementite.

It is possible that a mechanism of this nature is involved in the ready formation of cementite from martensite. It is particularly suggestive that a simple shear of alternate body-centred cubes gives a structure the general configuration of which resembles that of cementite. Contraction of the sides of faces from which carbon atoms are expelled, followed by approximate equalisation of the distances between neighbouring iron atoms, gives a structure of exactly the same type as that of cementite. Although the authors have had no opportunity of testing it experimentally, they have thought it of interest to advance this hypothesis, which appears to explain a very characteristic change.

ACKNOWLEDGMENTS.

The present work has been carried out at the Inorganic Chemistry Laboratory, the University Museum, Oxford, and the authors wish to express their thanks to Professor C. N. Hinshelwood, F.R.S., for laboratory accommodation and for many other facilities which have encouraged their research work. Thanks are also due to the Research Department, Woolwich, for supplying the steels from which the cementite was extracted.

Approval for publication has been granted by the Controller General of Research and Development, the Ministry of Supply.

REFERENCES. **

(1) H. Lipson and N. J. Petch: Journal of the Iron and Steel Institute, 1940, No. II., p. 95p.

(2) A. J. BRADLEY and A. H. JAY: Proceedings of the Physical Society, 1932, vol. 44, p. 563.

CORRESPONDENCE.

Dr. H. Lipson and Mr. N. J. Petch (Cavendish Laboratory, Cambridge) wrote: We have examined cementite obtained from a pure iron-carbon alloy; this had been homogenised and very slowly cooled to room temperature from 900° C., and the cementite was extracted electrolytically. Spectroscopic examination indicated only a trace of magnesium as impurity. The a and b axes were the same as in our original cementite, and the c axis was smaller by only 0.0005 Å. The difference from the results in the present paper cannot, therefore, be explained by decomposition, but must, presumably, be due to some other composition difference.

The attempt to find some relation between the martensite and cementite structures is certainly valuable, but the authors do not give sufficient information for their theory to be readily understood. It would be of great help if the orientation of Fig. 3 with respect to the crystallographic axes of cementite were given, as we have found it impossible to see from this figure how the atomic

arrangement shown in it resembles cementite.

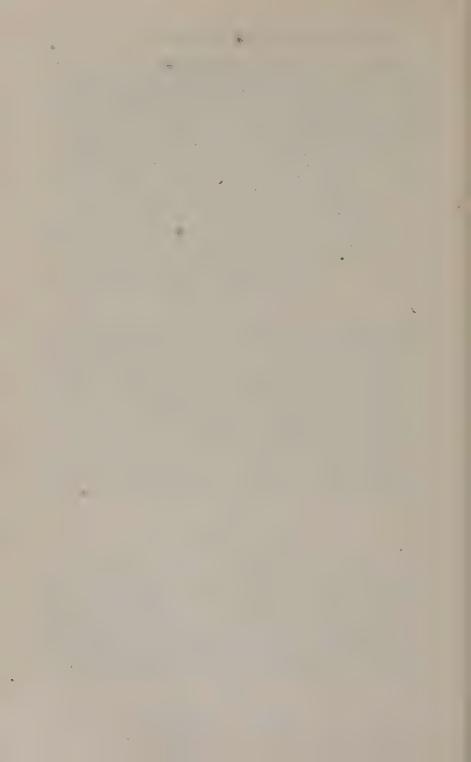
Dr. A. H. Jay (The United Steel Companies, Ltd., Stocksbridge, near Sheffield) wrote: To me the important part of the paper is the suggested scheme for relating the structure of iron with that of cementite by means of a simple distortion. From my own work it is clear that cementite can experience a distortion which changes the pattern until, with severe distortion, the original pattern is replaced by a few diffuse lines, the main one corresponding to the iron-carbon distance and/or the $1/\sqrt{2}$ iron-iron distance of cementite. The deformation of carbon steels provides an interesting study for the X-ray worker. Personally, I should regard the differences between the cementite structure of Lipson and Petch and that of the authors as due to different mechanical and heat treatment, as I have found that the "fully annealed cementite pattern" is not always obtained from furnace-cooled carbon (low-alloy) steels.

AUTHORS' REPLY.

The Authors replied: We must thank Dr. Lipson and Mr. Petch for their interesting communication, and hope that the factors affecting the exact lattice spacings of cementite will soon be more fully explained. In our own case, the unknown factor is the exact heat treatment of the steel from which the sample was extracted. The steel was sent to us for examination, and was described as having been forged and "slowly cooled in the furnace," but further details could not be obtained; in view of Dr. Jay's remarks, the mechanical and heat treatments may be responsible

for the different lattice spacings. We would explain that our diagram is simply an approximate drawing of the structure of Lipson and Petch. It is not easy to show the axes in the figure, but it may facilitate comparison if it is borne in mind that ckCemE is one of the small prisms shown by Lipson and Petch, and ck is parallel to the c-axis of the orthorhombic cell.

¹ Journal of The Iron and Steel Institute, 1940, No. II., Fig. 4, p. 102P.



THE WORK-HARDENING AND AGEING OF STEEL.*

By Professor J. H. ANDREW, D.Sc., and H. LEE, Ph.D., B.Eng. (University of Sheffield).

(Figs. 45 to 55 = Plates XXI, and XXII.)

ABSTRACT.

Experimental work was undertaken with a view to proving or disproving the hypothesis, formulated by one of the authors in 1938, that the cold-working of iron and steel gives rise to the formation of the γ phase. The authors are convinced that the experimental work described in this paper proves this contention. It is shown that carbon is dissolved during the work-hardening process, and that under certain conditions both austenite and martensite may form. A new theory of quench-agoing is suggested, and the subject of strain-ageing is also dealt with. The close correspondence between the changes produced in steel by cold-work and by quench-hardening is strong evidence in favour of the suggestions made. A new theory of the yield is developed, whilst the changes undergone during the extension of the tensile test-piece are shown to be dependent upon the total elongation and the condition of the carbide in the steel.

Introduction.

The increment in hardness and tensile strength produced by the cold-working of metals has received much attention from modern physicists, and the study of the lattice distortion associated with hardening has led to many new and ingenious theories. In 1938 one of the authors ⁽¹⁾ proposed a novel and somewhat revolutionary theory, the gist of which was that the cold-working of steel produced a state similar to that obtained by rapidly cooling the same material from a temperature exceeding the normal Ac₃ transformation.

This theory was based entirely on published data, and it was realised that, before it could be accepted by the metallurgical community, further experimental work was essential. It was thought that the methods of attack favoured by the metallurgist might usefully be employed, and if the results obtained were promising, X-ray examination could be brought to bear on the problem at a later date.

The very high tensile strength attained on cold-drawing a high-carbon steel (over 200 tons per sq. in.) was suggested as evidence that the carbide particles in the original undrawn material must play a vital part in the creation of this great strength. The most reasonable assumption to make was that, during the

^{*} Received February 7, 1942.

operation of wire-drawing, carbon was taken into solution on the planes of slip, giving rise to a network structure closely related to that obtained by a quench-hardening treatment. If the carbide particles play no part in the reaction, it is difficult to account for the great differences in strength produced by even small increments in the carbon content.

Similarity of properties is not necessarily a criterion of similarity of state, but if it can be shown that the characters of the transformations which take place during the reheating of the same material in the drawn and the quenched conditions, respectively, are similar, it must be admitted that evidence in favour of this theory has been evolved.

EXPERIMENTAL PROCEDURE.

In the earlier experiments, three plain carbon steels were selected; some test-pieces were cold-drawn to give different degrees of reduction, and others were quenched in iced brine from predetermined temperatures. Thermal and dilatometric heating curves were taken, in order that a comparison between the worked and quenched material could be made.

The thermal determinations were made in the usual manner, and the Miller dilatometer (2) was used for all dilatation work. the work progressed, it was evident that the effect of ageing must be taken into account, and although this phenomenon must be regarded as being distinct from the main issue, the relation between the ageing of the as-drawn and quenched specimens provided additional proof of the new hypothesis.

The steels selected for the earlier experiments were of the following compositions:

No.	C. %.	Mn. %.	· Si. %.	8. %.	P. %.
1	0.60	0.36	0.03	Trace	0.048
2	0.15	0.38	0.05	Trace	0.064
3	, 0.03	0.012	Trace	0.037	0.0035

Steel No. 1, Carbon 0.60%.—Dilatation curves of steel No. 1, after cold-drawing, are shown in Fig. 1; they are plotted in the order of increasing drawing reduction. The curve of the material in its original normalised state is linear up to the Ac, transformation. A 10% drawing reduction caused the material to expand by an amount equal to a-b; this expansion increased with increased cold-work. Upon heating the cold-drawn material, the return to the normal curve (i.e., normal for the unworked state) occurred at between 290° and 300° C. in every case. As the drawing reduction increased, a second inflection was observed in the neighbourhood of 150° C. Two other features are (a) the marked relative contraction beginning at temperatures between 595° and 645° C., culminating in the Ac, change (the temperature at which this contraction set in was lowered as the amount of cold-working was

increased), and (b) the increase in the total expansion between room temperature and the beginning of the Ac_1 transformation as the drawing reduction became greater.

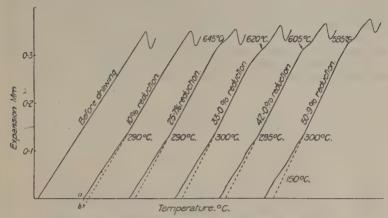


Fig. 1.—0.6% Carbon Steel, cold-drawn. Dilatation curves.

The dilatation curve for the same steel after quenching from 830° C. in iced brine is shown in Fig. 2, curve A (the effect of ageing will be dealt with separately later). Quenching produced an

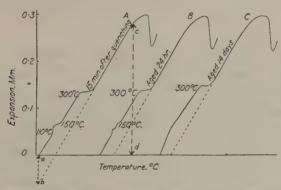


Fig. 2.—0.6% Carbon Steel, quenched from 830° C. in iced brine, and subsequently aged. Dilatation curves.

increase in length of the specimen equal to a-b. The return to the normal axis occurred at 300° C., as was the case with the cold-drawn specimens, whilst the inflection around 150° C. also corresponded in temperature with a similar change in the cold-worked

condition. No contraction immediately below the Ac_1 change was observed.

As the original length in the normalised state of all dilatation specimens was $1\frac{1}{2}$ in. and the machining was done accurately, it was possible to regard the measurement of the various changes in length undergone during heating as reasonably quantitative. Confirmation of this is to be found in the fact that when the initial expansion due to quenching, a-b, is added to the length c-d, the value obtained is equal to the increase in length of the original untreated specimen at a temperature just below the Ac_1 point.

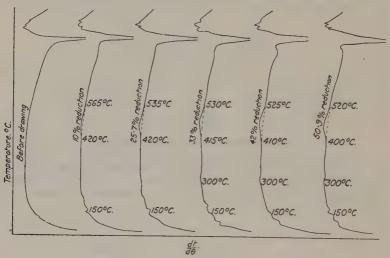


Fig. 3.—0.6% Carbon Steel, cold-drawn. Inverse-rate curves.

Thermal curves for the cold-drawn steel are given in Fig. 3, and for the quenched specimen in Fig. 4, curve A. In Fig. 3 there are indications of small transformations in the neighbourhood of 150° C., with a return to the normal slope at 300° C. There was also a transformation over a range of temperature within the limits of 400° and 565° C.; this transformation, which is of the nature of an evolution of heat, became more pronounced as the degree of reduction was increased. In the more highly drawn specimens there was an indication of a small absorption of heat immediately preceding the Ac₁ point. The thermal curve of the specimen quenched from 830° C., Fig. 4(A), has some interesting and peculiar features. Neglecting for the moment the marked inflections at 110° and 115° C., which disappeared on ageing, giving rise to a series of small kinks, a return to the normal takes place between 300° and 350° C., following upon a gradual evolution of heat over a range of temperature. Further, the small evolution

of heat over the range 400–560° C. again indicates the similarity between the as-drawn and the quenched condition. It would

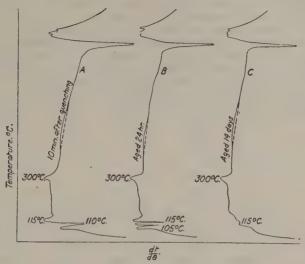


Fig. 4.—0.6% Carbon Steel, quenched in iced brine from 830° C., and subsequently aged. Inverse-rate curves.

appear from Figs. 3 and 4 that an evolution of heat begins at 150° C, and is completed at 300–350° C.

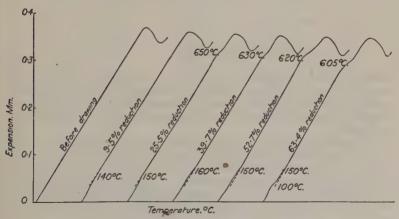


Fig. 5.—0.15% Carbon Steel, cold-drawn. Dilatation curves.

Steel No. 2, Carbon 0.15%.—Dilatation and thermal curves of this material in the cold-drawn state are shown in Figs. 5 and 6,

respectively. In Fig. 5, light passes on drawing produced a slight contraction, as measured by the dilatometer, and as the drawing reduction was increased it became changed into an expansion. On heating, the curve returned to the normal axis at approximately 150° C. In the specimen drawn $63\cdot4\%$, a low-temperature inflection is observed in the neighbourhood of 100° C. in addition to that at 150° C. The gradual contraction preceding the Ac₁ change detected in the higher-carbon steel is again apparent; it increased in magnitude with the degree of reduction. The total expansion at the completion of the Ac₁ change decreased with the increase in drawing reduction. The thermal curves, Fig. 6, have characteristics

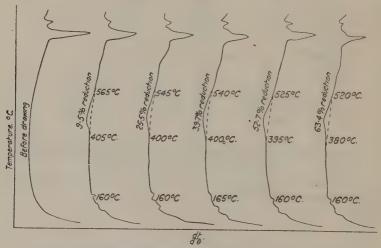


Fig. 6.—0·15% Carbon Steel, cold-drawn. Inverse-rate curves.

similar to those obtained with the 0.6% carbon steel, namely, a series of small inflections in the neighbourhood of 160° C., and a marked evolution of heat over the range $380\text{--}565^\circ$ C., this range becoming narrower and lower in temperature as the reduction increased.

Dilatation and thermal curves taken after quenching from 900° C. in iced brine are shown in Fig. 7, curve B, and Fig. 8, curve A. In Fig. 7 the only inflection is that at 165° C., at which temperature the slope of the curve becomes normal. Fig. 8 shows, in addition to an inflection at 170° C., a transformation of greater magnitude between 110° and 115° C.; this latter effect will be dealt with later.

Steel No. 3, Carbon 0.03% (Ingot Iron).—Dilatation and thermal curves after drawing to a 30% reduction, are given in Fig. 9, curve B, and Fig. 10, curve A, respectively. Transformations similar to

those for steel No. 2 were recorded. In Fig. 9 the curve B attains its normal slope at 160° C.; in Fig. 10, the thermal curve A after

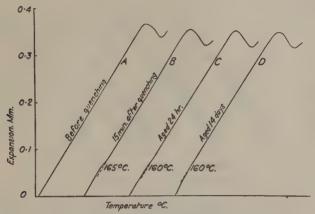


Fig. 7.—0.15% Carbon Steel, quenched from 900° C. in iced brine, and subsequently aged. Dilatation curves.

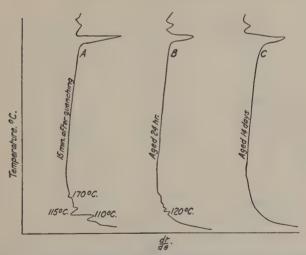


Fig. 8.—0·15% Carbon Steel, quenched from 900° C. in iced brine, and subsequently aged. Inverse-rate curves.

drawing shows that, in addition to the inflection at 160° C. and the heat evolution over the range 400–538° C., there was a marked transformation between 110° and 125° C. Quenching from 900° C.

produced (Fig. 11, curve B) an inflection at 160° C., at which temperature the curve returned to the normal slope. The thermal curve

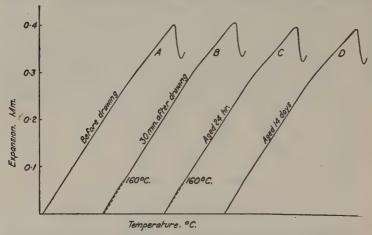


Fig. 9.—Ingot Iron, cold-drawn 30% reduction in two passes, and subsequently aged. Dilatation curves.

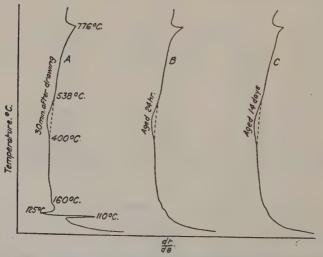


Fig. 10.—Ingot Iron, cold-drawn 30% reduction in two passes, and subsequently aged. Inverse-rate curves.

(Fig. 12, curve A) shows, in addition to the point at 165° C., an additional transformation at 110° C., this latter point disappearing on ageing.

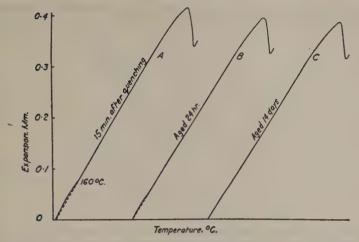


Fig. 11.—Ingot Iron, water-quenched from 900° C., and subsequently aged. Dilatation curves.

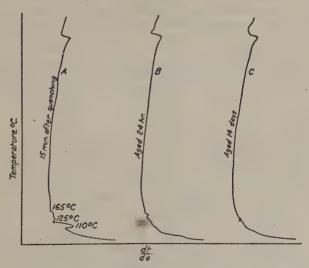


Fig. 12.—Ingot Iron, water-quenched from 900° C., and subsequently aged. Inverse-rate curves.

Summarising these transformations, in the dilatometric determinations low-temperature transformations occurred in each steel, both in the drawn and in the as-quenched condition, at similar temperatures.

Concerning the thermal analysis precisely the same remarks apply. For steel No. 1 (0.6% of earbon) the comparison was even

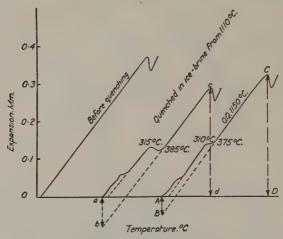


Fig. 13.—1·20% Carbon Steel. Dilatation curves before and 24 hr. after quenching in oil and iced brine.

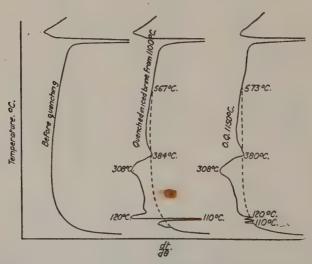


Fig. 14.—1·20% Carbon Steel. Inverse-rate curves before and 24 hr. after quenching in oil and in iced brine.

better, for not only was the transformation range 150-300° C. common to both the drawn and the as-quenched condition, but

also the definite heat evolution between 400° and 500° C. was

recorded in both the as-drawn and the quenched specimens.

 $1\cdot2\%$ Carbon Steel.—It is known that a steel containing $1\cdot2\%$ of carbon, when oil-quenched from a suitable temperature, will give the austenitic-martensitic structure. When water-quenching is resorted to the amount of austenite is less. In order to ascertain the effects produced on reheating an austenitic-martensitic structure, as compared with a structure consisting principally of martensite, a steel of this carbon content was quenched in oil from 1150° C. and in water from 1100° C.

Dilatation and thermal heating curves taken after this treatment, Figs. 13 and 14, serve to confirm the contention that oil-quenching conserves a larger amount of austenite than is retained

after quenching in water.

The expansion due to quenching, a-b, Fig. 13, is greater and the total expansion from 20° C. to the beginning of the Ac₁ change, c-d, is less in the specimen subjected to a water-quench. The transformations at $100-200^{\circ}$ C. are practically equal in magnitude in both cases, but the contraction at $300-315^{\circ}$ C. is considerably greater in the water-quenched sample. This excess contraction at 315° C. and also the smaller total expansion are definite indications that water-quenching produces a state of less density than a corresponding quench in oil. Martensite represents in a carbon steel the structure of the lowest density. Thermal curves of the water- and oil-quenched samples, Fig. 14, are similar with respect to the temperature of the transformations, neglecting for the moment the transformations around $110-120^{\circ}$ C. It should be noted, however, that the evolution of heat over the range $380-570^{\circ}$ C. is slightly greater in the oil-quenched state.

EXPLANATION OF TRANSFORMATIONS.

Neglecting for the moment the low-temperature changes, which disappear on ageing, the transformations requiring an explanation are the inflections at 150° and 300° C., both of which correspond with the completion of an exothermic transformation and are associated with a contraction. These are due probably to the decomposition of α and β martensite, respectively.

The gradual contraction which occurs at approximately 100° C. below the Ac_1 change in all the cold-drawn material may be caused by the equi-axing of the elongated crystals. It is reasonable to assume that a cold-drawn specimen would change in length when

the structure became equi-axed during tempering.

The heat evolution over the range which appears in the thermal curves of certain of the quenched and in the cold-drawn examples—so far as the authors are aware—has not been observed previously.

The only exothermic transformations that can occur in a carbon steel, so far as is known, are those associated with the γ - α trans-

formation, with or without precipitation of carbide, the latter condition being observed in the formation of martensite. Recrystallisation of deformed material would also be accompanied

by heat evolution.

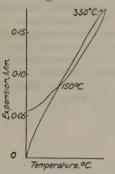
That the phenomenon of recrystallisation is a contributory factor in this exothermic reaction was proved by X-ray examination of the stressed and tempered specimens. Fig. 45, the X-ray pattern in the cold-worked condition, shows the broad rings due to grain breakdown. Upon annealing, no change was produced until a temperature of 400-500° C. was attained, when the well-defined doublets shown in Fig. 46 were produced. It was not until a temperature of 550° C. was reached that the pattern of the recrystallised material appeared (Fig. 47). There can, therefore, be but little doubt that the transformation in question is due partly to a crystallisation of the distorted material. The absence of any dilatometric change within this temperature range must, however; be accounted for, as recrystallisation unaccompanied by changes in other properties must give rise to a small contraction. If, however, superimposed upon this change, there should be a change from the denser γ to the less dense—fully tempered—α form, the two transformations occurring simultaneously, whilst they reinforce one another so far as the thermal effect is concerned, they might neutralise one another with respect to any change in length. The fact that a similar transformation was found in quenched steels does not necessarily negative this view, for it is possible, and indeed likely, that, after the decomposition of martensite, recrystallisation will follow immediately. If it could be shown that austenite persisted above 300° C. after the martensite had decomposed, it would follow as a necessary corollary that austenite must transform into the tempered state at a temperature above 300° C.

It is well known that certain alloy steels which have been rapidly cooled from a temperature above the uppermost critical point respond to a secondary hardening treatment, which consists in heating the steel to a specified temperature below the Ac₁ for a short period followed by normal air-cooling. The reaction brought about by this treatment is generally regarded as being the con-

version of residual austenite into martensite.

The dilatation on cooling an alloy steel from the secondary hardening temperature is marked by a sudden expansion between 150° C. and atmospheric temperature. A curve of this type was obtained by the authors with a steel containing carbon 0·32%, manganese 0·60%, nickel 4·5% and chromium 1·5%, after it had been reduced 20% by cold-drawing; the final and low-temperature expansion was considerable, being in the order of 0·2%. The dilatation curve of steel No. 1, after a drawing reduction of 46%, taken under the same conditions, is shown in Fig. 15, and the corresponding thermal curve in Fig. 16. The sudden expansion beginning at

 150° C. is well marked, as also is the thermal change, and the total increase in length is of the order of 0.1%.



Temperature, oc.

Fig. 15.—0.6% Carbon Steel, 46% reduction. Dilatation curve.

Fig. 16.—0.6% Carbon Steel, 46% reduction. Inverse-rate curve.

This experiment affords very strong evidence that the coldworking of a carbon steel is productive of austenite, or of a dense

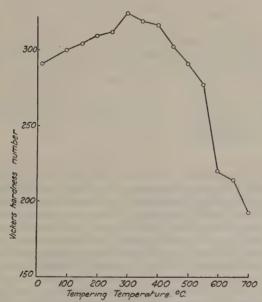
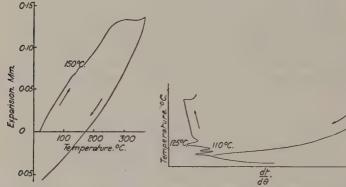


Fig. 17.—Vickers Hardness of 0.6% Carbon Steel, cold-drawn 40%, tempered at various temperatures for 10 min., and subsequently water-quenched.

phase which when decomposed at 150° C. results in a phase of less density than that of the steel in its fully tempered or annealed

condition. In order to ascertain whether any increment in hardness was produced by tempering, specimens of the same steel in the cold-drawn condition were tempered at increasing temperature intervals of 50° from 50° C. to 700° C. The results are plotted in Fig. 17; after tempering at 300° C. there is a hardness increment of just over 30 points Vickers, and it is only after heating to 500° C. that the hardness value becomes less than that of the original coldworked specimen. It would appear, therefore, that it is not until release of strain has been accomplished that any real softening of the specimen occurs. A dilatation test curve of steel No. 1 (carbon 0.6%) after quenching in iced brine from 830° C. is shown in Fig. 18 and the corresponding thermal curve in Fig. 19. It is evident that



Frg. 18.—0.6% Carbon Steel, quenched from 830°C. in iced brine. Dilatation curve on heating and cooling.

Fig. 19.—0.6% Carbon Steel, quenched from 830°C. in iced brine. Inverse-rate curve on heating and cooling.

the quenching treatment produced an almost completely martensitic state, for after the martensite had decomposed, as signified by the completion of the contraction in the neighbourhood of 300° C. on heating, the steel, on cooling to atmospheric temperature, returned to practically its original length before quenching.

As previously stated, the dilatation specimens were cut accurately to $1\frac{1}{2}$ in. in length, and it was inferred that the expansion between 20° C. and the beginning of the Ac_1 change could be regarded as a quantitative measure of the structural condition of the steel. When the specimen is first placed in the dilatometer, no matter what state it may be in—quenched or otherwise—the first reading may be taken as zero on the scale. Further, whatever may have been the state of any particular specimen at the beginning of the test, the actual lengths of all the specimens at the Ac_1 temperature would be the same. Supposing, for instance, that a martensitic

specimen was inserted into the instrument, martensite representing the maximum length obtainable; on heating, the martensite would contract, thereby greatly reducing the vertical distance as measured between the horizontal axis and the point representing the beginning of the Ac₁ transformation. This length would, as already stated, be short for a martensitic specimen and long for a steel of austenitic character. Thus, these lengths may be regarded as some

criterion of the structural properties of the steels.

On the basis of such measurements it would appear that the cold-drawing of steel No. 1 (carbon 0.6%) produced austenite in greater amounts than in steel No. 2, whilst water-quenching produced but little austenite. With respect to steel No. 2 (carbon 0.15%), cold-drawing would seem to produce martensite rather than austenite, but only in small amounts, as was also the case in water-quenched specimens of the same steel. The high-carbon steel containing 1.20% of carbon gave clear evidence that an oil-hardening produced a greater amount of austenite than did a water-quench.

CHANGES IN THE THERMAL E.M.F. WITH TEMPERATURE.

In view of the coincidence of certain specific thermal and dilatometric transformations on heating quenched and cold-worked steels, respectively, it was thought important to ascertain whether there were similar coincidences in other physical properties, and the changes with temperature of the thermal e.m.f. offered itself as a further possibility. The following two steels were examined:

No.	O. %.	Mn. %.	Si. %.	8. %.	P. %.	Treatment.
15CII	0.15	0.46	Trace	0.025	0.028	Normalised 900° C.
52C	0.51	0.89	0.15	Trace	0.086	Annealed 850° C.

Wires of these two steels, 0·2 in. in dia., in the lead-patented condition, were hot-pickled, blued and cold-drawn; they were then normalised at 900° C. and annealed at 850° C., respectively. The thermocouple consisted of a soft-annealed wire and a wire of the same composition in the hard-drawn state. It was obvious that a fused or soldered junction could not be used, whilst to twist the wires together would involve further cold-working. In the method adopted a hole was drilled at each end of a small cylinder of the same material as the wire and in the softened condition; the annealed and cold-drawn wires were inserted in one of the holes, care being taken to ensure a tight fit, whilst in the opposite hole a platinum-rhodium couple was inserted to measure the temperature, the two couple systems being within $\frac{1}{3}$ in. of one another.

Fig. 20 shows the e.m.f./temperature curves for steel 15CII

Fig. 20 shows the e.m.f./temperature curves for steel 15CII after different degrees of drawing reductions. A departure from the linear occurs between 100° and 150° C., as is also the case with

steel 52C, Fig. 21. No definite indications of other transformations are, however, shown. The general contour of the curves above 150° C. is peculiar and unexpected, in that there is a gradual increment in e.m.f. with increase in temperature, whereas a fall

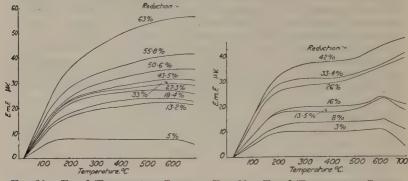


Fig. 20.—E.m.f./Temperature Curves for 0·15% Carbon Steel after different degrees of drawing reduction.

Fig. 21.—E.m.f./Temperature Curves for 0.52% Carbon Steel after different degrees of drawing reduction.

would be expected when the tempering of the drawn wire had been brought about. It must, however, be taken into account that as tempering proceeded, the position of the couple—cold-drawn/annealed systems—would move along the heated zone, giving a

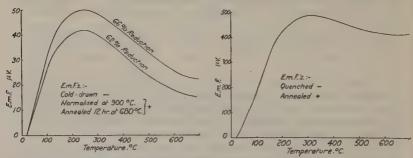


Fig. 22.—E.m.f./Temperature Curves for 0·15% Carbon Steel after colddrawing and annealing.

Fig. 23.—E.m.f./Temperature Curves for 0.52% Carbon Steel, waterquenched from 800° C.

value higher than the normal on account of the variable junction at any particular moment being heated to above the point of transformation of the drawn element. With steel 52C, a flattening of the curve occurs in the neighbourhood of 300° C., corresponding to a similar transformation as recorded by other means (i.e., thermal dilatation).

As neither normalising nor annealing will produce a completely unstressed condition, a further length of steel 15CII was normalised at 900° C. and annealed at 680° C. for 12 hr. This, when made into a couple with similar wire drawn 66% and 62% respectively, gave the values plotted in Fig. 22. Again, there is a deviation in the contour between 100° and 150° C., with a maximum value at 250° C. followed by a rapid fall. Fig. 23 shows the e.m.f. curve for the couple composed of completely softened wire and a length of steel 52C water-quenched from 800° C.; it indicates a transformation beginning at 300° C., as well as a change in direction between 100° and 150° C. All the wires used in the foregoing experi-

ments were aged before use for the e.m.f. determinations.

The changes which occur on heating in quenched and coldworked steels respectively are identical, so far as the transformation usually associated with the tempering of martensite is concerned. The same remarks apply to the secondary hardening effect revealed by a cooling curve following heating to 350° C. Trent (3) has shown, unmistakably, that martensite is formed in steel wires subjected to frictional forces, and it is a necessary corollary that the original constituent from which this martensite was derived is austenite. Dr. Trent kindly provided the authors with a sample of hard-drawn wire which had been split by a blow from a hammer. A micrograph taken near the split portion is shown in Fig. 48. The white band has the appearance of austenite; the hardness value was, however, 620 Vickers, compared with 420 for the surrounding structure. On tempering at 350° C., whilst the surrounding matrix was softened, the central band still remained at 600 Vickers, and on repolishing and etching gave the structure shown in Fig. 49. It may be that the original white band was austenite which was spontaneously transformed into martensite by the work-hardening due to the impression. It is known, however, that, on heating a martensite structure to 350° C., although a large contraction is brought about, the hardness is virtually unchanged. There is just the possibility, however, that the retention of the high hardness value may be due to an austenite-martensite transformation at 150° C. on cooling. A further indication of austenite formation on cold-working is seen in Fig. 50, in which the merging of the pearlite into a white constituent is very suggestive of carbon solution during cold-working. Fig. 51 shows the structure obtained after heating to 400° C., in which the white constituent has broken down into what appears to be martensite, whilst on fully tempering at 650° C., Fig. 52, pearlite and ferrite fill the field.

The foregoing experimental results provided strong evidence that, on cold-working, the carbide does pass into solution. For this to be possible it must be assumed that, during the process of slip, γ iron is formed along the planes of slip. To what this transformation is due—whether to the generation of heat locally over

the slip planes or to the mechanical change of a body-centred to a face-centred lattice-cannot be stated with certainty, but it is highly probable that if the austenite be formed in a carbon steel free from alloving elements, a large portion of it will transform

into martensite during cooling.

As a parallel to this, the work of Greninger and Mooradian (4) on β brass may be cited; the slip bands in deformed β brass, and also in certain copper-tin alloys, formerly believed to be mechanical twins, were shown to be manifestations of lattice transformation of a body-centred into a face-centred lattice.

AGEING PHENOMENA.

Reference to curves B and C in Figs. 4, 8 and 12 will show clearly the effect of ageing after quenching the three steels from above their

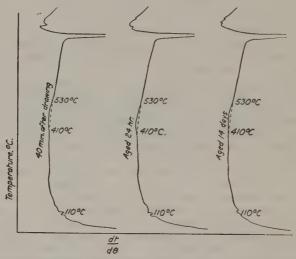


Fig. 24.—0.6% Carbon Steel, 29% cold-drawn, and subsequently aged. Inverse-rate curves.

Ac₃ transformation points, as revealed by thermal heating curves. Provided that a thermal curve is taken immediately or very shortly after quenching, a well-defined double point, which takes the form of a sudden absorption followed immediately by an evolution of heat, occurs in the region of 100-125° C. After remaining at atmospheric temperature for fourteen days these transformations did not appear.

The effect on the dilatation curves is shown in Figs. 2 (curves B and C), 7 (curves C and D) and 11 (curves B and \widetilde{C}); in time a slight contraction occurs at atmospheric temperature. The thermal

curve of steel No. 1 after cold-drawing (Fig. 24) gives no sign of any transformation associated with any ageing change, owing no

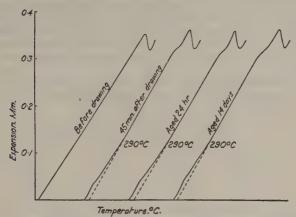


Fig. 25.—0.6% Carbon Steel, 29% cold-drawn, and subsequently aged. Dilatation curves.

doubt to the fact that during drawing the temperature momentarily rose beyond 125° C. Similarly, a negative result was obtained in the dilatation curve (Fig. 25). After cold-drawing, steel No. 2

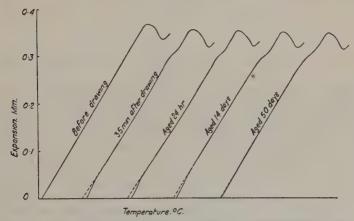


Fig. 26.—0·15% Carbon Steel, 43% cold-drawn, and subsequently aged. Dilatation curves.

(carbon 0·15%) gave an indication of an expansion on ageing (Fig. 26), whereas steel No. 3 (carbon $0\cdot03\%$) showed a contraction (Fig. 9), and it is known from other experiments that

the normal ageing change is associated with a contraction. The reason why steel No. 2 gave an expansion may be the transformation of a certain amount of austenite into martensite following the ageing effect. This steel invariably gave an indication of austenite formation in the dilatation curve taken to detect such a change, *i.e.*, heating to 300° C. followed by cooling, when an expansion occurred at 150° C. Fig. 27 shows the thermal characteristics of steel No. 2 on ageing.

The lowest-carbon steel (carbon 0.03%) was known to give both the maximum strain and quench-ageing effect, and it was

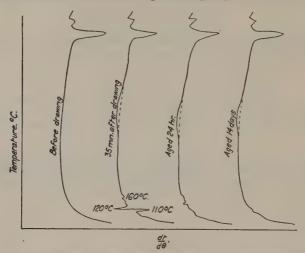


Fig. 27.—0·15% Carbon Steel, 43% cold-drawn, and subsequently aged. Inverse-rate curves.

decided to carry out further experiments with this particular steel. The thermal heating curves taken after cold-working and after quenching from 900° C., shown in Figs. 10 and 12, are similar, except for greatly intensified transformations in the low-temperature range of the cold-worked specimen. Dilatation curves after cold-drawing and after quenching from 900° C., Figs. 9 and 11, show a contraction with time at room temperature. On quenching from 700° C., however, marked differences were observed; the contraction, Fig. 28, was intensified, whilst the thermal curve, Fig. 29, showed one relatively large point with a number of minor inflections all of the nature of an absorption of heat. It is apparent, therefore, that a sub-critical quenching brings about a change at atmospheric temperature in which an absorption of heat occurs, without being followed by an evolution such as is found in steels quenched from above Ac₃ or in the cold-worked condition.

To explain ageing it is therefore necessary to define the true

meaning of these low-temperature transformations. The only transformations associated with an absorption of heat, so far as is known, are the $\alpha-\gamma$ change, the solution of carbon and the forma-

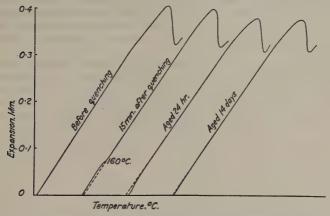


Fig. 28.—Ingot Iron, water-quenched from 700° C., and subsequently aged. Dilatation curves.

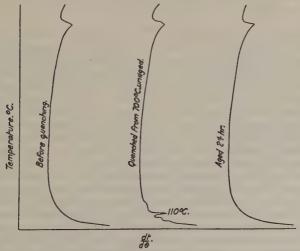


Fig. 29.—Ingot Iron, water-quenched from 700° C., and subsequently aged. Inverse-rate curves.

tion of Fe_3C . The possibility of the $\alpha-\gamma$ change can be dismissed, whilst the solution of carbon at this temperature is extremely unlikely. Only the formation of Fe_3C from free carbon atoms and

iron remains to be considered. Brodie, Jennings and Hayes, ⁽⁵⁾ and Maxwell and Hayes ⁽⁶⁾ give a value of —15,000 cal. per mol. for the heat of formation of Fe₃C, whilst Watase ⁽⁷⁾ and Roth ⁽⁸⁾ suggest a value of —4800 and —3500 cal. per mol. at atmospheric temperature, respectively. Umino ⁽⁹⁾ has shown that the specific heat of Fe₃C is greater than that of its constituent elements, hence the heat of formation of Fe₃C must decrease algebraically with the

temperature.

An excellent account of work in this field has been given by Schwartz, (10) who made a calculation of the heats of formation of Fe₃C at temperatures from 250° to 1000° C. based on Naeser's (11) and Roth's (8) data. In α-iron the heat of formation has a value of the order of -4000 cal, per mol. at temperatures between 100° and 150° C. As the temperature rises above 500° C. this value increases rapidly, but even at 900° C. it remains negative, becoming only slightly exothermic in γ-iron at 900° C. Carbon atoms in solution in either α- or γ-iron are said to be distributed in the interstices between the iron atoms, and this would necessarily bring about an expansion of the lattice. Ohman. (12) for instance. has shown that in quenched steels the lattice parameters of either γ- or α-iron increase as a function of the carbon content. From the authors' experimental results, and the work of others, it would appear that the absorption of heat and contraction on ageing of a low-carbon steel sub-critically quenched are due to the formation of Fe₂C.

Kurdjumow and Kaminsky $^{(13)}$ were able to show by X-ray examination that the contraction at 100° C. corresponded with the decomposition of the α-iron/carbon solution into free Fe₃C and α-iron, whilst Kurdjumow and Sachs $^{(14)}$ confirmed that after 2 hr. tempering at 100° C. no less than 95% of the α-iron/carbon solution decomposed into carbon-free iron and Fe₃C. Heindlhofer and Bain $^{(15)}$ suggested that in a martensitic structure the carbon atoms are atomically dispersed and exist interstitially, greatly warping the ferrite lattice. They also pointed out that the preprecipitation condition of Fe₃C in iron in a simple molecular

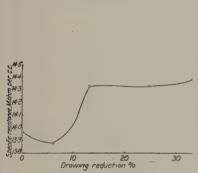
form will cause the greatest hardening effect.

It would appear, therefore, that the evolution of heat following immediately after the absorption is due to the actual precipitation of the carbide molecule, in contradistinction to its formation, which occurred with absorption of heat. The results obtained by the authors indicate that all steels, whether in the quenched or the cold-worked condition, are subject to the phenomenon of ageing. If, however, the original hardness of the worked or quenched material is of a high order, the increase in hardness resulting from the formation and precipitation of Fe₃C from α solid solution is not sufficient to bring about a marked increment in the hardness as a whole. In a low-carbon $(0.03\,\%)$ steel which has been sub-critically quenched the ageing seems to stop after the

first stage, namely, after Fe₃C has been formed; the actual precipitation which normally follows this reaction in a steel quenched from above Ac₃ or in cold-worked material would tend to effect a softening. The degree of softening compared with the hardening in the pre-precipitated range may vary according to the composition and conditions of treatment. Further, the presence of austenite in a cold-drawn or quenched specimen might conceivably modify the reaction. The greater ageing effect, as measured by an increment in hardness, in a sub-critically quenched than in a cold-worked specimen may also be partially attributed to the heating due to drawing being equivalent to a mild tempering treatment. As the maximum hardness is obtained after the preprecipitation stage of the reactions, the increased strength of this

5000 25,500

4000 20 400



Unaged
Aged I month
Permeability
Remanence
Coercive Force

t Fig. 31.—0.6% Carbon Steel. Effet

Fig. 30.—0.6% Carbon Steel. Effect of drawing reduction on the electrical resistance.

Fig. 31.—0.6% Carbon Steel. Effect of drawing reduction on the magnetic properties,

labile structure may be due to the attraction between the carbon atoms and atoms within the iron lattice, giving increased rigidity to the complex lattice as a whole. When actual precipitation occurs, the relief of stress will bring about a partial softening, as is known to be the case, for it is usual to find that if the time of ageing be prolonged, the hardness value gradually falls after reaching a maximum. Precipitation, rather than being associated with increased hardness, actually occasions a softening.

Even with low-carbon ingot iron it is known that carbon precipitation does occur as the temperature is raised to above 150° C., but it would appear that it does not take place at atmospheric temperature; the reason for the absence of any evolution of heat at a definite temperature is that the whole of the carbon is in solution, whereas in the higher-carbon steels the free carbide probably serves as nuclei for the spontaneous precipitation.

An interesting observation, for which, so far, no explanation can be found, has reference to the lower degrees of reduction. It

will be noticed that unless the drawing reduction is greater than 10%, the change associated with the equi-axing of the crystal grains, *i.e.*, the contraction immediately preceding the Ar_3 change, is absent. Other peculiar effects have been noted by other workers in this field with respect to small amounts of cold-work. Figs. 30 and 31, which depict the effect of drawing reduction on the electrical resistance and magnetic properties, respectively, support the contention that small amounts of cold-work produce a change in properties which is not magnified by further cold-work. At 5% reduction, Fig. 30, there is a decrease in electrical resistance; this

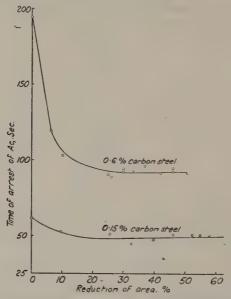


Fig. 32.—Relation between the Drawing Reduction and the Time of Arrest of Ac₁.

suggests that small reductions merely serve to consolidate the material. The sudden increase in resistance at 12% reduction, followed by little further change in this property up to 30% reduction, is remarkable. In the magnetic properties, Fig. 31, at 5% reduction there is a considerable fall in permeability and a rise in the coercive force, which again suggests that this small amount of cold-working must increase the density of the material and that cold-working, as usually understood, only begins at a later stage of reduction.

Fig. 32 shows the relation between the degree of drawing reduction and the time of arrest at Ac_1 . Here again—with respect to the 0.6% carbon steel—there is a marked change in the neighborhood.

bourhood of 10% reduction. It would appear that, for some reason or other, the rate of solution of the carbon is doubled by a small amount of cold-work. In the lower-carbon steel the effect is only slight.

THE YIELD POINT IN STEEL.

In 1900 Muir ⁽¹⁶⁾ published an interesting account of his experiments on the effect of stressing steel to the yield point followed by tempering at 200° C. Muir used a steel containing 0.35% of carbon and 1.6% of manganese. He stressed it to the yield point and allowed the full yield elongation to take place; if then the specimen was heated to 200° C., a re-test showed that, not only did the material behave elastically again up to the yield, but the yield point was raised considerably. By repeating this treatment three times, the yield was raised from an initial value of 38 tons to 60.5 tons per sq. in. If, after stressing to the yield followed by a removal of the load, the specimen was reloaded without tempering, it

behaved plastically from the start of loading.

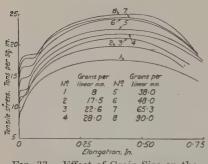
Edwards, Jones and Walters (17) carried out a series of experiments similar to the foregoing, using a steel of much lower carbon After stressing to the yield they annealed their specimens at 250° C. and re-tested. They attributed the increment in yield value and maximum stress to ageing, and came to the conclusion that ageing was a phenomenon associated with the carbon in steel. The present authors' experiments which brought to light the marked thermal transformations between 100° and 125° C. on heating a cold-worked or quenched steel and the complete disappearance of these transformations after ageing at atmospheric temperature for a specified time, coupled with the secondary hardening effect produced on cooling a cold-worked sample previously heated to between 200° and 350° C., raised a doubt in their minds as to whether the increments in yield and maximum stress obtained by Edwards and his colleagues were a true ageing effect or a secondary hardening phenomenon. Andrew and Trent (18) showed that a mild steel in the quench-aged condition was softened by heating to 250° C. Further, Edwards, Jones and Walters supported the suggestion of Kuroda (19) that the yield point was dependent upon the carbon content of the steel. In 1925 Edwards and Pfeil (20) published their work on the relation between tensile properties and crystal size, as measured by the number of grains per square millimetre, and proved that, not only was the small grain size associated with an increased yield and maximum stress, but the yield elongation was also a function of the grain size.

In view of the importance of the subject, the authors thought that a repetition of certain experiments relating to tensile properties and grain size might be useful, and they prepared a series of testpieces suitable for the purpose. Details of their preparation and of the results obtained are given in Table I. and the results are

Table I.—Steel M2. Pretreatment and Mechanical Properties; Grain Size.

Carbon 0.08%; manganese 0.55%; silicon 0.08%; sulphur 0.019%; phosphorus 0.039%. Normalised at 930° C.

						(
No.	Rolling Reduc-	Annealing Temp.	Grains	Elastic Limit.	Yield Point.	Max. Stress.	Breaking Stress.	Elonga-
	tion.	and Time.	per mm. Tons pe		r sq. in.	Tons per sq. in.		%-
1	10	720° C. 12 hr.	8.0	8·62 8·60	9·20 9·00	$17.60 \\ 17.20$	14·50 14·10	37.5 $36.\overline{5}$
2	12	720° C.	17.5	9.60	11.34	19.76	16.70	33.7
		12 hr.		9.60	11.11	19.56	16.05	33.3
3	15	720° C. 12 hr.	22.6	$10.70 \\ 10.50$	11.90 11.89	$21.05 \\ 21.23$	$16.60 \\ 17.00$	$\begin{array}{c c} 36\cdot 4 \\ 37\cdot 4 \end{array}$
4	20	720° C.	28.0	11.10	12.61	21.82	16.87	38.0
		12 hr.	ſ	11.10	12.88	21.81	16.74	38.4
5	30	720° C. 12 hr.	38.0	$12.00 \\ 12.20$	$14.32 \\ 14.77$	$22.46 \\ 22.51$	17·45 17·15	$\frac{38\cdot0}{37\cdot5}$
6	70	720° C. 12 hr.	48.0	13·00 13·00	16·16 16·63	23·93 24·15	18·56 18·80	36·3 36·0
7	70	620° C.	65.3	13.55 13.65	17.88	24.25	18.66	36.5
		12 hr.			18.00	24.39	18.51	35.9
8	70	620° C. 6 hr.	90.0	$14.00 \\ 14.05$	18.60 18.86	24·80 ·25·00	$\begin{vmatrix} 18.90 \\ 18.20 \end{vmatrix}$	36·0 36·5



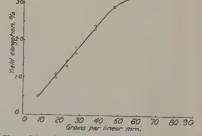
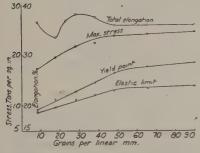


Fig. 33.—Effect of Grain Size on the Load-Extension Curves of 0:08% Carbon Steel.

Fig. 34.—Effect of Grain Size on the Yield Elongation of 0.08% Carbon Steel.

plotted in Figs. 33 to 36. Fig. 33 depicts the load-extension curves for the different specimens, and Fig. 34 shows that as the grain size decreases the yield elongation increases. The values for the elastic

limit, yield, maximum stress and elongation, in relation to grain size, are graphed in Fig. 35. With the exception of the figures for the total elongation, which vary in no regular manner, owing most probably to the unevenness of stretch of the specimen along its measured length, the other properties show a regular increase up to 50 grains per linear millimetre, after which, with further reduction in grain size, the curves become asymptotic. The elongation, when measured at the point of maximum stress, was almost identical for all the specimens, clearly showing that the uniform stretch before necking had taken place was quite uninfluenced by variation in grain size. The relation between the yield stress and yield elongation, Fig. 36, indicates that the yield extension is proportional to the maximum stress attained before yield commences.



20-15 to 15 20 2:5 30 3:5 Yeld elangaran %

Fig. 35.—0.08% Carbon Steel. Elastic limit, yield, maximum stress and elongation in relation to grain size.

Fig. 36.—0.08% Carbon Steel. Relation between yield stress and yield elongation.

The relation between the yield elongation and maximum stress is linear or approximately so, indicating that the increment in maximum stress with yield elongation is due to the cold-working effect

brought about by slip within the yield.

Test-pieces of steels Nos. 1 and 2 were stressed to slightly beyond the yield, the stress was removed, and the load was again applied until further plastic deformation had set in; this cycle of stresses was repeated. The graphs obtained, Figs. 37 and 38, indicate that even when the load is alternately applied and released until the maximum stress is eventually attained, the load-extension curves follow the normal course, provided that no time is allowed for ageing. It is known that had ageing been allowed between the different cycles, curves of a very different character would have been obtained. The relation between the yield, elongation and grain size suggests that movement occurs at the yield along planes of easy slip; if the grain size is excessive, slip will be almost continuous. In a polycrystalline material, easy slip will be confined to crystals suitably orientated, and the chances of suitable

orientation will increase as the number of grains per square milli-

The reason why slip in steel is not continuous at the yield, bringing about final fracture at the yield stress—as is the case with

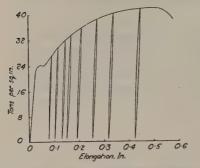


Fig. 37.—0.6% Carbon Steel. Elongation with alternately applied and released load.

Fig. 38.—0·15% Carbon Steel. Elongation with alternately applied and released load.

pure molybdenum, which also crystallises in the body-centred form—may be that iron, unlike molybdenum, is able to undergo an allotropic transformation. That such a transformation is involved at the yield point is suggested by the dilatation curve of steel No. 3 (carbon 0.03%) on cooling from 200° C. after being

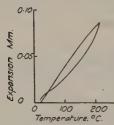


Fig. 39.—Dilatation Curve of Ingot Iron pulled to the yield point (13·19 tons per sq. in.). Elongation 2·10%.

stressed to the yield at normal temperatures The low-temperature expansion associated with the $\alpha-\gamma$ transformation is quite marked. On stressing to the maximum stress, this low-temperature expansion was greater. Quenching the same steel from 900° C. gave a normal curve. Similar effects were observed in steels Nos. 1 and 2 (carbon 0.6 and 0.15%, respectively), in both of which the low-temperature expansion was observed. On the assumption that during slip at the yield films of the γ phase will form along the planes of slip, and that as slip proceeds they will partially transform to minute crystals of a phase, further slip along the original planes of easy glide will cease, and because of

the strengthening effect of the transformation an increased load will be necessary to bring about further extensions of the test-piece. Between the yield and maximum stress, slip will occur along the more difficult planes of slip, and a similar transformation will occur, but to a greater degree. Further, if Fe₃C be present along the glide planes, it will be taken into solution with the ulti-

mate formation of austenite and its first decomposition product, martensite, the strength of the material increasing until final rupture. Fig. 40 shows clearly that carbon is dissolved during the yield and also during the plastic flow which takes place between

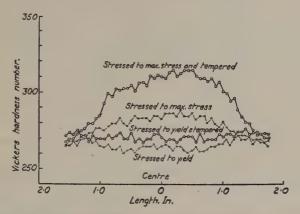


Fig. 40.—Hardness Values along an Oil-Quenched and Tempered Bar of 0.6% Carbon Steel.

the yield and the maximum stress. This diagram records hardness determinations along a test-bar of steel No. 1 (carbon 0.6%) which had been oil-hardened and tempered. In one case the bar was stressed to the yield and in the other case to the maximum stress. The test-piece was sectioned along its length and hardness impressions were made. The sections were then tempered at 300° C. and the measurements repeated. The curves clearly show that at the centre of the bar the increment in hardness brought about by the secondary hardening treatment attained the maximum. The same section tested in a similar manner, but in the normalised state, gave a similar but less pronounced hardness increment, showing clearly that the greatest effect was obtained when the carbide of iron was in the more finely dispersed state, which would assist in its more rapid solution.

A hardness curve of a nickel-chromium steel containing nickel 1.6%, chromium 1.5%, manganese 0.62%, molybdenum 0.3% and carbon 0.35% taken along the length of a test-piece sectioned vertically after pulling to destruction and tempering at 300° C. gave the results reproduced in Fig. 41. Tempering brought about a general increment in hardness, which increased towards the fractured end where the elongation was greatest. Near to the actual fracture there was a marked fall in the hardness value, and a very considerable increase in this area after tempering, an increment, 65 Vickers, clearly indicating the formation of austenite at

the fracture with its resulting transformation into martensite on tempering. In order to ascertain the effect of initial heat treatment on the variation in hardness along the length of a piece pulled

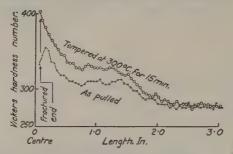


Fig. 41.—Hardness Values along a Bar of Nickel-Chromium Steel (CHMS) pulled to destruction and tempered.

to destruction, the above steel was given various heat treatments; the effects on the tensile properties were as follows:

Specimen		Yield Point.	Max. Stress.	Elonga- tion on	Reduc-
No.	Treatment.	Tons per			Area. %.
VAGS 6	Normalised 800° C.	58.02	98.77	15.0	46
8	O.H. 800° C., & 475° C., A.C.	75.54	90.45	13.0	48
9	O.H. 800° C., T. 550° C.	74.97	99.64	14.8	50
10	O.H. 800° C., T. 680° C.	37.43	61.21	22.0	58.7

Hardness curves taken along the length of the specimens are shown in Fig. 42. In VAGS6, which gave an elongation of 15%, there is a gradual increase in hardness to near the point of fracture, where there is a slight drop in the figure. In VAGS8 and VAGS9 there is a gradual diminution in hardness towards the point of fracture, whilst VAGS10, which had an elongation of 22%, has a large peak in the hardness value, followed immediately by a large drop, amounting to over 100 points Vickers, near to the fractured end. The high hardness values of VAGS6, as compared with VAGS9, are difficult to account for.

These curves show that it is the capacity to elongate which determines the change in hardness, and it is well known that in cold-drawing the change in properties is sudden as a certain minimum value of cold-work reduction is passed. Not only will the elongation affect the final values, but also the capacity of the carbide to be taken into solution in the γ phase produced.

These results emphasise that the maximum stress depends, amongst other factors, on the elongation during testing and on the degree of dispersion of the carbides. The microstructure at and near the point of fracture may be very different from that of the original unbroken bar, apart from any structure produced by the mere drawing-out of the test-piece, known as fibring.

It has been suggested that face-centred iron is formed during the yield in a tensile test, and that its partial decomposition into a phase of a martensitic character is responsible for the increment

in strength following the yield elongation.

It was thought that a measurement of magnetic permeability carried out on a tensile test-piece, as testing proceeded, might furnish some useful information. Test-pieces of steels Nos. 1 and 2 were machined to give an overall length of $8\frac{1}{2}$ in., with a 6-in. parallel portion and a diameter of 0·169 in. The shoulders were made to fit exactly in the grips of the Hounsfield tensometer, care

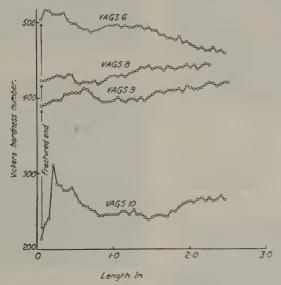


Fig. 42.—Hardness Values along Bars of Nickel-Chromium Steel (VAGS), after various treatments.

being taken to avoid air gaps. The ratio of length to diameter was 35 to 1, which was sufficient to eliminate any demagnetising

effect due to the proximity of the ends.

It could not be certain that the bar would break in the centre, so three search coils, consisting of 50 turns each, made of 41-gauge fine copper wire, were equally spaced and wound uniformly over the specimen; they were connected in series. A thin layer of silk ribbon was placed between the specimen and the coils, and a further covering of silk wound on the coils insulated the search coil from the primary or magnetising coil made up of 240 turns of thick copper wire.

The testing arrangement consisted of a magnetising circuit and a Hounsfield tensometer, which also served for carrying out the

tensile test. The primary coil was excited by a current from an accumulator, the current being adjusted by an accurate ammeter and a rheostat. A ballistic galvanometer was used for measuring the magnetic induction.

Before carrying out the test, a complete magnetisation curve was worked out for each specimen, from which the field strength for maximum permeability was calculated, and the corresponding current was assigned and maintained for the test. For steel No. 2,

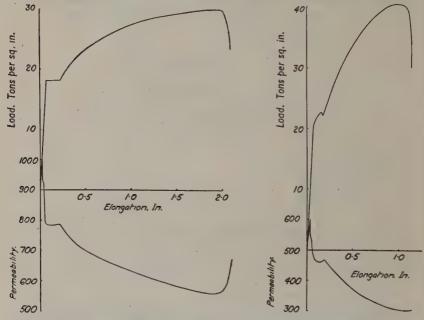


Fig. 43.—Load-Extension and Load-Permeability Curves for 0.15% Carbon Steel.

Fig. 44.—Load-Extension and Load-Permeability for 0.6% Carbon Steel.

a current of 0.5 amp. was used and 0.75 amp. for steel No. 1, corresponding to a field strength of 10 and 14 Oersted, respectively.

The small error due to the decrease in diameter of the specimen during its elongation was calculated and allowed for, and no

appreciable heating of the specimen took place.

The load-elongation curve was registered at increments of I ton per sq. in. up to the yield, after which readings were taken at every 0.04-in. increment in length. Corresponding readings of the magnetic induction were taken. The results obtained are shown in Figs. 43 and 44. The load-extension curve is similar but almost the mirror image of the load-permeability curve in Fig. 43;



Fig. 45.—Cold-worked condition. Broad rings due to grain breakdown.



Fig. 46.—After annealing at 400–500° C. Well-defined doublets.



Fig. 47.—After annealing at 550° C. Pattern of recrystallised material.

Figs. 45 to 47.—X-Ray Patterns of 0.32% Carbon Steel after 58% reduction by cold-drawing.



Fig. 48.—Hard-Drawn Steel Wire, split by hammer blow. Near split portion. \times 600.



Fig. 49.—Hard-Drawn Steel Wire, tempered at 350° C. \times 800.



Fig. 50.—As cold-drawn.



Fig. 53.—Pulled just beyond elastic limit. Unetched.



Fig. 51.—After heating to 400° C.



Fig. 54.—Pulled to yield limit. Curved slip bands shown without etching.

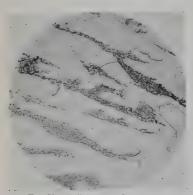


Fig. 52.—Fully tempered at 650° C.
Figs. 50 to 52.—0·32% Carbon Steel after 58% reduction by cold-drawing. × 1000.

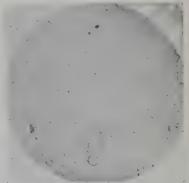


Fig. 55.—Pulled to yield point, then heated at 650°C, for 1 hr. Recrystallisation along grain boundary.

cold-drawing. \times 1000. Figs. 53 to 55.—0.07% Carbon Steel. \times 150. (Micrographs reduced to two-thirds linear in reproduction.)

[Andrew & Lee. [To face p. 185 p. in Fig. 44 the correspondence is evident but not quite so close. One curious feature common to both curves is the sudden rise in permeability within the elastic limit, corresponding with a maximum value at 5 tons for the mild steel, and 7.5 tons for the other. In the lower-carbon steel, the increase in permeability within this range was quite considerable, being an increase of 95, whilst for the second steel it was of the order of 71. After this maximum the permeability fell rapidly to the yield, and then remained almost constant with a tendency to increase during the yield elongation, after which there was a rapid fall to the maximum load. With the mild steel there was a rapid and considerable increase in permeability between the maximum load and breaking load.

Ewing (21) stated that when a steel wire was stretched in tension the magnetic induction was increased. This effect was later dealt with by Wall, (22) who showed that the permeability of a steel wire was greatly improved under a tensile load well within its elastic limit. It would seem probable that, whereas an applied stress of this amount is insufficient to promote lattice distortion, it may in some way or another increase the alignment of the magnetic poles within the metal, with the consequent increase in permeability. This peak value in the magnetic permeability may possibly corre-

spond more with the true elastic limit of the steel.

The constancy of the permeability over the yield is at first sight surprising, especially in view of the suggested formation of face-centred iron during the yield elongation. The horizontal portion at the yield is virtually an increase in permeability, for by extrapolation it should fall. On the assumption that during the yield films of γ -iron are formed along the lines of slip, and that, owing to crystal rotation, slip takes place largely in the direction of the applied force, the system at the completion of the yield may be regarded as being similar to a bundle of magnetic iron wires separated by a thin film of a non-magnetic substance. Wall (23) showed that correctly treated ingot iron had a magnetic permeability of the order of 5500, and the same wire coated with manganese powder of a thickness of 0·002 in. gave a permeability of more than double this value.

In the same way, the permeability of a pure nickel wire was increased from 1400 to 3250 by simply coating it with a thickness of 0.003 in. of pure copper. In general, it would appear that a coating of a non-magnetic material greatly increases the permeability. It is obvious that if face-centred iron is produced on the slip planes during yield, this will behave as a non-magnetic, or less magnetic, film and in this way enhance the permeability value.

As the load was increased to beyond the yield, there was a regular drop in permeability up to the maximum stress. This can be explained as being due to slip taking place on all slip planes and at all angles with respect to the direction of flow, resulting in the formation of non-magnetic γ -iron across the normal lines of force.

In the low-carbon steel (Fig. 43) a pronounced increase in permeability occurred during the final necking-down of the specimen; this is believed to have been brought about by the formation of martensite due to the drastic cold-working during this final stage of testing. In the higher-carbon steel, where austenite has been found to form at the last stages of testing, no such effect is apparent.

A mild steel containing 0.07% of carbon was treated so as to produce a large grain size, and then stretched in the testing machine to just beyond the elastic limit. Micro-examination of the polished but unetched section (Fig. 53) revealed a relatively thick grain boundary. On stretching to a further degree—to just within the yield—strain lines appeared (Fig. 54). These results indicate that the first effect of a stress just above that of the elastic limit is to bring about a movement at the grain boundaries, and that this grain boundary movement is synchronous with the elastic limit. Provided that there is sufficient interlocking at the boundary surfaces to withstand further stress without fracture, slip will then follow, and the strengthening associated with such movement will then take place.

On tempering the section stressed to within the yield at 650° C., recrystallisation was found to start at the boundaries (Fig. 55).

SUMMARY AND CONCLUSIONS.

It has been shown experimentally that the properties of a coldworked steel are similar in many respects to those of a steel of the same composition in the quench-hardened condition. Both quenching and cold-working produce an increase in hardness, maximum stress and electrical resistance. In a high-carbon steel, colddrawing will produce a much higher maximum stress than can be obtained by the most drastic quenching. The fact that an increase in carbon content up to a certain optimum figure results in a proportionate increase in maximum stress, which may attain a value of over 200 tons per sq. in. for a particular degree of drawing reduction, leads to the definite conclusion that carbon must play an important part in this increase, and the only possible conclusion is that carbon must be taken into solution during the cold-working process.

The solubility of carbon in α -iron is known to be low; therefore, it is a necessary corollary that γ -iron must form during coldworking. Whether the final density of the material be reduced or increased as the result of cold-working, at the point in the die or the rolls where the maximum reduction is effected compressive forces must momentarily come into play. According to the theory of Le Chatelier, a compressive force will assist in the formation of a denser phase, which in this particular case would be γ -iron. Further, the heat generated along the planes of slip can quite conceivably be sufficient to raise instantaneously the temperature locally to a

sufficient degree, not only to promote the $\alpha-\gamma$ change but also to bring about the solution of carbon. The two effects, due to pressure and increase in temperature, will therefore combine to bring about this transformation. The amount of experimental evidence in favour of this hypothesis is considerable. The transformations recorded by thermal and dilatation curves on heating quenched or coldworked steels present several points of similarity, namely, (a) a transformation usually associated with the decomposition of martensite, (b) a transformation in the neighbourhood of 150° C., (c) a thermal evolution over a range of temperature between 400° and 600° C. associated with recrystallisation and with the decomposition of austenite, and (d) the simultaneous absorption and evolution of heat between 100° and 125° C., which disappears on ageing.

The most convincing proof of the formation of austenite on cold-working is perhaps the property of secondary hardening on tempering and the expansion in the neighbourhood of $100-150^{\circ}$ C. It is difficult to imagine any reaction other than the $\alpha-\gamma$ transformation that could effect such an expansion. The development of austenite or martensite bands by means of a sharp blow is convincing evidence, since martensite can only be formed by the decomposition of austenite. Micrographs shown by the authors, and others recently published by Trent, (3) leave no doubt as to the

validity of this argument.

The phenomena of quench-ageing and strain-ageing have been dealt with very fully, and experimental data would seem to show that the much greater increment in hardness resulting from quenchageing, as compared with strain-ageing, is due to an actual formation of Fe₃C in single molecules, without its precipitation, and therefore without the formation of a less dispersed state. The strain in the lattice brought about by this labile state is, it is suggested, the cause of the marked increase in strength and hardness. In a cold-worked steel or in one that has been quenched from above Ac3, it is reasonable to assume that sufficient nuclei of free Fe₂C would be present to bring about a precipitation immediately following its formation, and, whereas this disperse precipitation would increase the hardness by interference with slip, the effect produced would not be as great as that of the non-associated molecules holding the iron lattice in a stressed condition. It would appear that ageing occurs in all cold-worked and quenched steels to some extent, but, as only the ferrite is affected, when the amount of this constituent decreases and at the same time the normal hardness increases owing to the greater carbon content, the total effect of ageing becomes less.

Tempering at 200–350° C. after cold-working cannot be regarded as an ageing treatment, for in a carbon steel the greater part of the carbide is deposited and coalesced within this temperature range. Such a treatment is essentially associated with secondary hardening.

Mechanical tests undertaken to determine the relation between grain size and mechanical properties have shown for the particular low-carbon steel employed that, below a certain minimum grain size, curves depicting the relationships between grain size and

property become asymptotic.

Certain interesting relationships have been found. For instance, if the elongation at the point of maximum stress is measured before necking has taken place, the value is constant for all sizes of grains. This feature must be of some significance, but it is difficult to explain; it may be that the total length of movement on all the slip planes added together is a constant—that is to say, the fewer the slip planes, the greater the distance of glide on these planes. When the crystal size is small, a greater load is necessary to produce the same elongation, owing to the increased angularity of the glide

planes.

It was also found that the maximum stress bore a linear relation to the length of the yield. This is of particular interest, for it leads to the conclusion that the changes undergone during yield are responsible for the maximum stress attained. This particular section of the investigation led the authors to a new theory of the vield. In a body-centred metal such as molybdenum, the loadextension curve is similar to that of a low-carbon steel with respect to the elastic portion and the yield, the difference being that fracture occurs after stretching has taken place at a constant load which corresponds to the yield point in steel. The so-called "plastic" part of the curve is absent. Molybdenum undergoes no allotropic transformation, and it is suggested that this difference in the form of the curve is due to the fact that iron and steel in the body-centred form begin to extend at a certain load—i.e., the yield—and when this extension takes place, γ-iron begins to form on the slip planes, but undergoes almost simultaneous partial transformation to the α-form. The result is the formation of crystals of a-iron at the glide planes, with the resultant strengthening of the whole. When slip on the planes of easy glide is completed or stopped by this formation of small crystals, further extension can only be brought about by the more difficult glide planes coming into action. As this phase of the test would be associated with considerable crystal rotation, the formation of these layers of small crystals would increase more rapidly, and their inclination one to another would also add to the strength of the material under test. If carbon were present, it would, by going into solution, add a further increment to the load necessary for continued extension until rupture finally occurred. At the point of rupture, where the final reduction in cross-sectional area is so marked, there are indications that there is a perceptible formation of the face-centred form, and that final fracture occurs in the planes of a face-centred lattice.

There is evidence to show that, even after stressing to the yield

and removing the load, a small amount of iron is retained in the γ-state, a dilatation curve of a specimen stretched to the yield showing a definite low-temperature expansion on cooling after reheating to 200-350° C. This effect was considerably greater when the specimen was loaded to the maximum stress.

Further proof of this contention was afforded by the determination of the magnetic permeability of a tensile test-piece during the mechanical test; during the yield there was a virtual rise in permeability. That this was due to the formation of non-magnetic films such as austenite along the cleavage planes is supported by the work of Wall, (23) who showed that the coating of iron wires. with a non-magnetic metal gave a considerable increase in permeability.

The application of these theories to the results obtained with mechanical tests gives rise to the obvious conclusions that the breaking stress of any steel depends largely upon the reactions which are taking place within the plastic portion of the loadextension curve. The total elongation undergone during test and the degree of dispersion of the carbides in the original test-piece are essential factors leading to the final result, which is dependent upon the formation and retention of austenite and its decomposition product, martensite, during test.

In conclusion it may be stated that all data obtained have shown that the chief factor involved in cold-working, whether cold-rolling, wire-drawing, cold-pressing or mechanical testing, lies in the formation during these processes of austenite.

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DISCUSSION.

Professor F. C. Thompson (The University, Manchester): The authors have broken completely new ground in attempting to provide a comprehensive theory of the effects of cold-work on steel. They have gone further and have shown new facts for which such an explanation is quite urgently required. I am in full agreement that, revolutionary as the theory may at first sight appear, there is no a priori ground for rejecting it. As the authors point out, it is compatible with the Le Chatelier principle, and there is no fact known to me, at any rate, which precludes the possibility that on the slip planes temperatures are attained, temporarily and locally, sufficient to raise the material above the carbon change point.

It has long been recognised in a general way that there is a close relationship between many of the properties of cold-worked and of quenched steel. The authors have now shown that even in the case of hitherto unsuspected detail the analogy holds. They have, therefore, come to the conclusion that it is not unreasonable to expect some similarity of constitution between the cold-worked and the quenched material. Up to this point I am in complete agreement with them. They then go on to suggest that this similarity of constitution arises from the fact that during the cold-working process the iron takes carbon into solution, and the austenite so formed is either retained or, alternatively, is reconverted into martensite. I do not deny that possibility, but there is an alternative explanation which I want to argue, namely, that the very close similarity between the two sets of properties arises from the fact that in martensite itself, as I think McCance was one of the first to emphasise, the α-iron is in a condition of extreme strain.

There is another point to be considered. If this theory is necessary, I think it is essential that the authors should show that in the cold-working of steel there is some difference of an absolute character from the effects that are obtained in the cold-working of alloys in which, so far as we know, there is no possibility of any phase change occurring. In that respect, I should like to suggest that on the penultimate page of the paper, where they deal with their ideas of the formation of new, and presumably very small, crystals on the slip planes, that is exactly what has been shown to take place in single-phase alloys as the result of deformation alone. X-ray fragmentation leads almost exactly to the result that the authors reach by a relatively complicated path.

The authors have rightly laid very considerable emphasis on the influence of the carbon in raising the tensile strength of the drawn material. I think that one can see some sort of justification for that on perfectly general grounds. The hard carbide particles must interfere, and interfere appreciably, with the general flow of the ferrite during the cold-working operation. Herbert and I showed in a rather pictorial way what I have in mind in our short note on the use of the Hele-Shaw apparatus in connection with the study of the flow of metals. It would appear reasonable to believe that such deformation would result in far more severe distortion of the α -iron lattice, and therefore, presumably, in increased

hardening.

It is not very clear from the paper how much austenite the authors imagine is formed. It may be very difficult for them to give an answer to that question. It is also not quite clear how far they regard that austenite as being retained, or, on the other hand, as being reconverted into martensite. It is, therefore, a little difficult to discuss the question of volume and magnetic changes, but, if I may make a suggestion in connection with the latter, I do hope that at some time the authors will turn their attention to the question of the coercive force, which, at any rate in my opinion, is the most useful criterion there is in such a connection. The difficulty with the permeability is that of all the magnetic characteristics it is the most profoundly affected by the exact nature of the magnetic circuit.

The authors are badly handicapped in one obvious direction. At first sight one would say that if any appreciable amount of γ -iron is formed, X-ray photographs should reveal it; but, with a comparatively small amount of γ -iron, admixed with a predominantly large amount of α -iron in a condition of extreme strain, the

investigation becomes a matter of extreme difficulty.

It seems to me that some, at any rate, of the authors' results can be explained on pure stress bases. There is a good deal of evidence that when a material is cold-worked the resulting strains are in part of a rather temporary character, disappearing or being reduced by standing at room temperature or by reheating to a comparatively low temperature, and, on the other hand, in part of a far more permanent kind, stable up to the recrystallisation temperature. The study, for instance, of season-cracking is a quite typical example. By very low-temperature annealing it is possible to remove those stresses in the brass, or whatever it may be, to which season-cracking is due, although the strains resulting in the increased hardness of the material are not reduced, and in fact by low-temperature treatment that hardening can actually be increased.

The biggest difficulty that I find in the theory is in connection with the known facts with regard to the behaviour of austenitic steels when they are cold-worked. If any change of structure does occur as a result of the cold-working, it is, so far as my knowledge goes, invariably in one direction. The austenite is converted into martensite. I know of no case where the reverse change takes place; and it would appear, therefore, not unreasonable to believe that deformation, so far from facilitating the formation of austenite, actually tends to make that austenite unstable.

I may summarise my views by saying that, while I agree completely with the fundamental possibility of the authors' theory, I

must at present record a verdict of "not proven."

I cannot finish, however, without saying that I regard this as a piece of pioneer work of real importance which deserves the best that we can give it in the way of criticism. It is something far too good to be merely passed by with easy compliment and facile praise.

Dr. Hugh O'Neill (London, Midland and Scottish Railway Co., Derby): Professor Andrew's theory stimulates one to take stock of existing knowledge on the hardening of steel, but the first difficulty encountered is a certain diffuseness in the proposal. It is claimed that when steel is cold-worked either in tension or by drawing or rolling, then martensite is produced. I presume that this means the development of martensite throughout the mass of the specimen, but more detail as to what is supposed to happen would be welcome. Is the conversion to martensite only on the slip planes, and is it progressive with increasing cold-work? It is known that martensite itself can be considerably strain-hardened; therefore, do the authors believe that the martensite claimed to develop at an early stage of working becomes itself hardened by the later stages of deformation? Is this the reason why they correctly point out on p. 186 P that the drawing process may result in a higher strength than the quenching process? By higher strength the authors mean the nominal tensile stress, but this property might well be considered on the basis of true stress at fracture, whilst it is probable that the diamond hardness of a quenched eutectoid steel would be higher than that of a drawn eutectoid steel.

The next reaction to the theory is that it seems to be unnecessary. Apparently it originated in a difficulty of explaining a tensile strength of 200 tons per sq. in. in cold-drawn high-carbon steel. The authors state that "the carbide particles in the original undrawn material must play a vital part" and that "it is difficult to account for the great differences in strength produced by even small increments in the carbon content." No one will deny that the carbide plays a part in connection with the tenacity of drawn steel wire, but there seems to be no necessity for requiring that it should become martensite in the process. The presence of 7.5% of zinc in copper allows its diamond hardness to be increased 2.9 times by drastic cold-rolling, whereas 30% of zinc gives a hardness increase of 4.2 times without the necessity of solution effects being involved. I have no difficulty in visualising the generation of sufficient slip-plane temperature during deformation to develop austenite and subsequently martensite, because the quantitative estimates of Russell have shown that even melting temperatures might arise on the slip planes of iron crystals during deformation.

1 T. F. Russell, Journal of The Iron and Steel Institute, 1923, No. I., p. 497.

Again, it may be said that the theory is unnecessary, since the high tenacity of drawn high-carbon wire is only normal in proportion to the tensile strength of the material from which it is drawn. Table A might serve to show that both body-centred and face-centred pure metals, conglomerates and solid solutions will generally treble their initial nominal tensile strength if subjected to heavy reduction in the cold; consequently a patented and drawn eutectoid steel wire would be expected to reach a tenacity of 200 tons per sq. in.

If the authors cannot accept this view, then, in default of their direct proof of the theory, one must examine their supporting indirect evidence. On p. 187 p, "the most convincing proof" advanced is the secondary hardening observed on heating drawn steel at a relatively low temperature, and Fig. 17 reveals that this is about 10%. It is well known, however, that a similar effect is observed in strain-hardened metals which contain no carbon at

Table A.—Influence of Heavy Cold-Reduction on Initial Nominal Tensile Strength.

Metal.	Nominal Tensile Strength. Tons per sq. in.		Ratio.
	Before Drawing.	After Drawing.	
With heavy drawing.			
Ingot iron (Adam)	20	60	3.0
Free-cutting mild steel (Adam)	36	112	3.1
Eutectoid steel (Adam)	4 90	250	2.8
Drawn 75% reduction.			
Copper	14	28	2.0
$67/\overline{33}$ brass solid solution .	21	54	2.6
62/38 brass conglomerate .	25	55	$2 \cdot 2$

all. The hardness values of mild steel completely decarburised in hydrogen, of electrolytic copper and of α brass all show increases of about 10% when the cold-worked material is heated in the vicinity of 200° C. Once again there seems to be no necessity for the carbon solution theory.

No one denies, of course, that there are many similarities in the behaviour of steel hardened in the two ways under discussion. L. Aitchison ¹ made a study of the subject in 1923, and the following statement is of interest in connection with the present "novel" theory: "The suggestion has frequently been made that austenite may be produced in a cold-worked steel during the work-hardening operation... no such change seems to be necessary in order to account for the properties of the work-hardened metal.... Burger has examined thin drawn wires and found that the space lattice of the material was not altered by such drastic working...."

¹ L. Aitchison, Iron and Steel Institute, Carnegie Scholarship Memoirs, 1923, vol. 12, p. 113.

After enumerating the similarities in properties, Aitchison showed, however, that there are two differences. In the first place, long exposure to 100° C. only slightly affects the limit of proportionality of drawn steel, but considerably modifies that of quenched alloy steel. In the second place, fatigue stressing lowers the limit of proportionality of drawn steel, but raises that of quenched alloy steel. Perhaps the authors will be good enough to indicate their attitude to these remarks of Aitchison.

The concluding difficulty in accepting the theory is that quenching a pearlitic steel to martensite produces a *rise* in the Meyer n value (ball indentation test) from, say, $2 \cdot 25$ to $2 \cdot 36$, whereas harden-

ing by cold-work causes a fall to a limiting value of 2.0.

Dr. A. H. Jay (The United Steel Companies, Ltd., Stocksbridge, near Sheffield): Like Professor Thompson, I agree in principle with the authors' theory, but I cannot go all the way with them. I do not wish to discuss the paper in detail now, and should like

to send in a written commentary.

Recently I examined a severely deformed low-alloy steel by means of X-rays and found a small amount of austenite in the deformed surface layer. I do not know whether this could or could not have been seen under the microscope. I should like to point out that it is possible to cold-work the surface of an austenitic steel and produce a ferritic layer. (Hadfield's 13% manganese steel is one exception; it remains austenitic.) The same austenitic steel can be made to give a distorted austenitic layer by increasing the rate of deformation. These facts are revealed by X-ray photographs. One important factor in deformation processes is, therefore, the rate of deformation.

As a physicist, I find Table I., Figs. 34 and 36 very informative. What I have done is to work out what I call a "unit crystal dimension," one which is primarily responsible for yield strain. (The exact value of this unit is not of significance here and will be discussed elsewhere.) If I then plot the reciprocal of the unit crystal, i.e., the number of unit crystals per centimetre, against the tensile properties, I obtain straight-line relationships. This means that, although the authors use different reductions in thickness, from 10% to 70%, and annealing temperatures and times of 720° C. for 12 hr., 620° C. for 12 hr. and 620° C. for 6 hr., the properties of these samples can be represented by straight-line relationships. Thus the increase in elastic limit is proportional to the reciprocal of the unit crystal size, or to the number of these units in, say, 1 cm., or the test length, and the same applies to the yield stress; further, the actual deformation at yield is proportional to the number of these crystals. In other words, each crystal plays a similar part.

Since this paper was published, I have made a few tests to try to find this austenite formation in ferritic steels pulled to fracture,

but so far I have not been successful. I am not altogether surprised, because I can examine material, let us say, to a depth of 0.001 in. below the surface, and in these cases this cannot be taken as representative of the body of the material. What I do find, and what I found previously, but have not been able to explain, is that a carbon steel or a low-alloy steel with, say, 0.3-0.5-0.8% of carbon, stressed past the yield point and finally to fracture, shows changes in the X-ray pattern of the cementite. The lines no longer appear in the same position, and the change from that given by the annealed steel increases with increasing deformation. I do not know whether it is significant—it may be—that with severe deformation the only lines which I have been able to find, in addition to those of α-iron, are lines which correspond to certain interatomic distances of the cementite structure. In fact, these lines correspond to an iron-earbon distance and/or to a $1/\sqrt{2}$ iron-iron distance. These facts suggest that crystals of cementite are progressively distorted and ruptured into fragments and that these assume the form of a plate, rod or particle, finally approaching in size that of a Fe₃C molecular grouping.

In conclusion, I cannot see the reason why the authors' theory should be wrong, but I should not like to say that every test which the authors have made to prove their hypothesis is explained by

the hypothesis.

Dr. C. H. Desch, F.R.S. (Vice-President; Iron and Steel Industrial Research Council, London): The authors have shown very great ingenuity, and have provided us with many important matters to discuss. If I put forward a few reasons why I am not able myself to accept their explanation, it is simply with the object

of getting further discussion later on.

I do not think that it is necessary to have a theory of this kind for the work-hardening of steel, because the behaviour of a steel wire is so like that of non-ferrous metals, as Dr. O'Neill has already mentioned. Tungsten wire can be drawn to a tensile strength of 300 tons per sq. in., although it has no allotropic change and there is no question of anything being taken into solution. Supposing that the \(\gamma \) form has been formed, and then that has been converted to martensite and so produced hardness, the question arises of how much martensite would be required to give the observed hardness. It happens that the hardness of mixtures of martensite with ferrite and pearlite has been determined for a good many steels; taking a 0.6% carbon steel, if that were drawn to give a strength equivalent to 600 Brinell hardness it would require 60% of martensite. That, of course, would be very easily seen under the microscope; but actually I do not think that we see anything of the kind.

A very interesting photograph by Trent is reproduced in the

¹ Journal of The Iron and Steel Institute, 1940, No. II., p. 229 p.

paper, but I think that there the conditions are different. band of martensite is produced by sudden deformation, by a blow, and under those conditions the deformation is virtually adiabatic. There is no time for heat to go away; a very high temperature is reached, and it is quite natural that the critical point should be

The argument that the denser phase must be formed during rolling cannot, I think, be maintained. In the process of rolling, the material is not subjected to pure hydrostatic compression; it is compressed in one plane and extended in others. Pure hydrostatic compression does, of course, favour the formation of the denser phase, and we know that every increase of about 1000 kg. per sq. cm. corresponds with a lowering of the critical point by 8° C. It would require an enormous load to bring the transformation point down to anything like room temperature.

The analogy with β brass given on p. 170 P is not. I think, correct. The brass is in the quenched state, and is metastable. Coldworking, in accordance with the ordinary rule, makes it go over to the stable state. But these steels are in the stable state, and the argument here requires that they should go over to the metastable state by cold-working. The behaviour of \$\beta\$ brass is similar

to the behaviour of 30% nickel steel or austenitic steels.

As regards the possible production of a high temperature on the layers during slip, I think it is quite reasonable to assume that such a thing might happen; in fact, for many years past I have maintained the Beilby view that, under those conditions, the melting point is actually reached and the liquid form is produced. That is very much objected to on many grounds, and I do not want to be too certain about it, but it would fit in equally with the authors' views.

I am not sure that the resemblances between the two sets of curves for work-hardened and quenched steels are very much more than fortuitous. The 150° C. point is very frequently connected with the presence of nitrogen, and I am surprised that nitrogen is not mentioned, because Professor Andrew was one of the pioneers in investigating the influence of nitrogen on steel, and we know that the separation of nitrogen at that range has a very great effect on the mechanical properties.

Those are just a few of the arguments that I want to put forward which should be taken into account in this discussion. the same time, we are greatly indebted to the authors for putting, forward a bold and ingenious explanation. I should like to know why they think it necessary to put forward such an explanation for steel when nothing of the kind is required for metallic tungsten.

CORRESPONDENCE.

(Figs. A to C - Plate XXIIA.)

Dr. A. G. QUARRELL (The University of Sheffield) wrote: With regard to Fig. 14, I wonder if the authors are justified in drawing the conclusion that there was an evolution of heat over the range 350-570° C, in the water-quenched and oil-quenched specimens of the 1.2% carbon steel. It appears to me that the dotted lines drawn on the heating curves of the quenched specimens are of little significance. Since these lines were drawn with the object of showing more clearly the thermal transformations which occurred as a result of previous quenching, the comparison curve should surely have been drawn parallel to that of the unquenched steel. When the curves are drawn in this way it is clear that the heating curve for the water-quenched specimen shows three main evolutions of heat with maxima at 120°, approximately 150° and 308° C., respectively, followed by a relative absorption of heat with a maximum at 380° C. This apparent absorption is probably due to the fact that from 110° to 350° C, there was a continuous evolution of heat by the specimen, so that the temperature difference between the specimen and the furnace was abnormally small from 350° to 460° or 470° C., where the curve returned to the "normal" for the unquenched specimen. The curve for the oil-quenched specimen is similar, except that the sharp evolution of heat at 120° C. is absent.

It will be realised that these observations in no way detract from the soundness of the arguments put forward by the authors in support of their view that austenite is formed during the coldworking of steel. The similarity between the properties of the cold-worked and quenched specimens is remarkable, and, taken with the results of the numerous other experiments described by the authors, seems to leave no reasonable room for doubt as to the truth of the austenite theory.

Mr. A. Allison (Messrs, J. J. Habershon & Sons, Ltd., Rotherham) wrote: The study of the similarity between cold-worked and quenched material has produced evidence which, I think, amply supports this and other theoretical matters. The diverse methods employed by the authors supply further corroboration.

The existing theory of cold-work seems to be that, under stress, the crystals are ruptured into blocks, which slip along cleavage planes, producing the dark lines so familiar to the microscopist concerned with cold-worked steel.

From a mechanical standpoint it would be expected that the material after cold-working would be weaker if some crystals were ruptured, but the reverse is the case.

Two questions have therefore to be answered concerning (a)



Fig. A.—Ends of Upset Bars. × 1.



Fig. B.—Structure of Body. \times 100.



Fig. C.—Structure of Cold-Worked End. \times 100.

Figs. A to C.-Microstructural Change due to Upsetting. (See Allison's contribution.)



the adhesion of the blocks to each other and the cohesion of the mass, and (b) the visibility of the dark lines.

On a larger scale, in shearing mild steel billets, it sometimes happens through imperfect working that the shearing is incomplete, but the pieces of the billet still adhere strongly to each other.

Without mentioning any specific temperatures, the authors propound that the greatly increased strength was due to solution of carbide and formation of austenite and martensite. That at all events concedes a considerable local increase of temperature. I not only agree, but would go further and suggest that the well-known physical phenomena of liquefaction and regelation occurred, the latter amounting to a very rapid quenching. That would carry with it solution of carbide and the age-hardening effect.

The high tensile strength and hardness produced by drawing steel with 0.6% of carbon can be explained by the very great mechanical forces operating on minute layers, which are subjected to the extremely rapid quenching effect of the mass on thin layers.

The visibility of the slip planes in a mild steel can be explained by the presence of martensite and a differential etching effect.

I can supply further evidence in support of the authors' views. A steel similar to No. 3 employed by the authors, viz, ingot iron, was lightly drawn to a flat bar about $\frac{7}{8}$ in. by $\frac{1}{8}$ in. in section. The ends were then upset cold by two quick pressures into the shape shown in Fig. A. The structure was examined at the points marked by small circles. Fig. B, taken on the body, is quite typical of the material. Fig. C, on the cold-worked end, is largely

recrystallised.

It is well known that cold-worked ingot iron does not respond very much to sub-critical annealing, and, in my view, the micrograph shows that, within the crystals, there must have been a temperature of, say, 900° C. at least for recrystallisation to have taken place. Also, since the resistance to deformation was at its lowest in so pure a material as ingot iron, when a refractory higher-carbon material is cold-worked, a temperature at least as high might be reached along the slip planes, or higher, in view of the magnitude of the mechanical forces necessary for deformation, concentrated on very small planes. I would like to have the authors' views on this.

I therefore agree with the authors' conclusions that the physical results produced by cold-working are bound up with the formation of austenite and/or martensite. At the same time, while much useful information has been obtained on cold-working, I still think that a complete statement of the physical and chemical considerations involved and the consequent phenomena has yet to be made.

Dr. A. H. Jay (The United Steel Companies, Ltd., Stocksbridge, near Sheffield), in a further contribution, wrote: The procedure of extrapolating back a portion (approximately linear) of the expan-

sion curve to room temperature is ingenious, and certainly brings out any low-temperature expansion irregularities. There is one danger to this practice, as it is applied in the present case, namely, that the departure (a-b) at room temperature of the actual dimensions from that judged by the extrapolation curve is assessed as the "cold-drawing expansion." It appears to me that, contrary to the authors' statement, the expansion curve does not return to the normal curve at, say, 300° C. Examination of the curves in Fig. 1 shows that the amount of expansion between room temperature and 300° C. is identical in all cases, i.e., the expansion up to 300° C. is normal in amount, and that in the range 300-600° C. where the expansion is regular, the expansion coefficient actually increases with increasing percentage reduction and, of course, cannot be regarded as normal. The lower rate of expansion from 600° C. to the Ac₁ point is probably associated, as the authors state (p. 163 P, sixth paragraph), with the equi-axing of the elongated crystals. It seems to me that it may be due to the crystalline growth of the cementite. Thus the increased total expansion between room temperature and the Ac, point as the percentage reduction becomes greater (Fig. 1) is undoubtedly brought about by the larger expansion coefficient in the 300-600° C, temperature range as the percentage drawing increases; this part of the curve is not normal.

I cannot understand the reference to the dilatation curve (Fig. 2, A) in respect of the length changes a–b and c–d. It is true that (a–b + c–d) equals the expansion of the normalised steel, but on what basis was the length c–d chosen? The point c represents not the Ac₁ point, but one approximately 100° C. below it. This does not agree with the statement (p. 156 P, second paragraph) "just below the Ac₁ point."

The magnitude of the inflections at 110–150° C. and at 300° C. in the expansion curves are different for the two conditions, cold-drawn and water-quenched (Figs. 1 and 2), and this is confirmed by the thermal curves (Figs. 3 and 4). This obvious difference is

not commented on by the authors.

The striking difference between the expansion curves of the cold-drawn steels is that the 0.6% carbon steel shows an increased expansion while the 0.15% carbon steel has a lower expansion with greater percentage reductions. The changes above 600° C are similar for the two steels, while those at the lower temperatures are smaller for the 0.15% carbon steel. Further, the expansion rate in the range $300-600^{\circ}$ C is not changed by cold-drawing, in contrast to the marked changes for the 0.6% carbon steel.

A 0·15% carbon steel does not appear to be a good sample for obtaining support for the authors' hypothesis, in that the low-temperature change is very small and the contraction phenomenon (600–730° C.) is well marked in the cold-drawn samples and absent in the water-quenched, while the thermal curves (Figs. 6 and 8, A)

are really quite different in respect of the fine details under examina-

tion. The ingot iron is likewise a disappointing choice.

The dilatation curves on the $1\cdot 2^{\circ}$ /, carbon steel (pp. 162 p and 163 p) are very interesting and appear to prove the statement regarding the relative retaining power for austenite produced by water- and oil-quenching. It is therefore very surprising to find that, whereas the dilatation curves differ essentially at the 300–380° C. change, the thermal curves are here remarkably similar, but strikingly different at the lower temperature.

It is our experience that rapidly quenched low-alloy nickelchromium steels are martensitic (see p. 165 P, third paragraph). X-ray photographs taken within a few hours of quenching show only a distorted body-centred cubic pattern with no γ -iron. Austenite is retained with slower rates of cooling, and with very slow cooling

the $\gamma \longrightarrow \alpha$ transformation would be complete.

Now, referring to Fig. 15, can the authors say why, if austenite is present, this does not change to a less dense form on heating? On this same point, the dilation curves of the 0.6% carbon steel (pp. 165 P and 166 P) for the water-quenched and cold-drawn conditions are very different. Can the authors give the reason?

In the e.m.f. tests, it is appreciated that the effective hot junction will move along the wires away from the hot junction, but it is not clear why the two sets of curves, Figs. 20 and 21 and Figs. 22 and 23, should be so different when in each case an annealed wire was used with a cold-drawn wire of the same composition. What experimental changes were made to obtain the differences?

It is interesting to note that a hammer blow on a hard-drawn wire was required to produce the effect shown in the micrographs, Figs. 48 and 49. Could this be taken to mean that microscopic austenite is formed only in cases of very severe local deformation?

There does not seem to be any doubt that where the deformation is both rapid and heavy the temperature of the steel may become sufficiently high (i.e., above the Ac_3 point) by the conversion of mechanical energy to heat energy for some Fe_3C to become reactive with γ -iron and, by virtue of sufficient solution of carbon in the γ -iron, to allow of the retention of this γ -iron in the "as-cooled" condition. It is probable that any visibly retained austenite, with or without martensite, would be associated more with areas of approximately eutectoid composition than with the original α -iron grains.

The statement (p. 176 P, first paragraph) that "cold-working, as usually understood, only begins at a later stage of reduction" (i.e., beyond 5-10%) might be explained more fully. Figs. 30, 31 and 32 do not seem to fit in with this conclusion, since it is low-

percentage reductions which have such a marked effect.

Referring to Fig. 32, have the authors made a measurement of the area enclosed by the Ac_1 arrest? Is there a temperature broadening of the Ac_1 arrest with increasing percentage reduction? If cold-working disrupts carbide-rich areas, as well as the α -iron

grains, then it is to be expected that with a more broken or dispersed form, with greater surface contact with the α -iron, the rate of reaction at Ac₁ will be increased, and, further, that the initial rupture will be most effective, later stages of deformation having less effect.

Referring to p. 180 P, last sentence, "Further, if Fe₃C be present along the glide planes . . .", this idea fits in well with that postulated by me, and there seems every possibility that carbide is present within the α -iron grains, possibly in the form of a network. This idea is not unreasonable, since all the carbon or carbide cannot diffuse out of the α -iron to the boundaries in the time allowed by a normalising or even a so-called furnace cooling. This carbide would have been formed as a three-dimensional skeleton, with an orientation controlled by that of the parent grain and of a size governed by the rate of cooling and the alloy content. The results shown in Figs. 41 and 42 have been examined by X-ray analysis and were discussed at the Meeting.

The magnetic tests show surprising results. Here, the explanation is not accepted as final, but it is admitted that it is

difficult to find a satisfactory alternative.

This paper stimulates thought on the changes undergone in the cold-deformation of carbon and low-alloy steels.

Dr. E. W. Fell (Birmingham) wrote: This interesting paper and the new theory described by the authors again focus attention on the plastic yield and on the problem of the yield point in steel. The plastic yield consists mainly of two parts: The horizontal part in the stress-strain diagram, during which the plastic distortion is propagated along the metal at about constant stress, and the part in which the metal as a whole yields continuously till fracture occurs. I will confine myself here to a discussion of the changes occurring in the first part only—the sudden and extensive initial yield.

The assumptions that films of the γ phase form along the planes of slip at the yield and that as slip proceeds they will partially transform to minute crystals of α phase, which finally arrests movement along the planes, is a useful one in conjunction with existing yield-point theory. There is, as yet, certainly no theory to explain the sudden and remarkable yielding of iron and steel which may be regarded as a final one, and it is not possible to deduce or predict the presence of such yielding in any metal, being given only the properties of the crystals as known at present. All that apparently can be said is that aggregates of α -iron crystals possess many more crystallographical planes to favour sudden mass slipping (according to the maximum-shear-stress theory) compared with other metals. This was the explanation given in my own work on the subject, and the authors in their paper explain why the mass slipping is brought to an end.

¹ Fell, Iron and Steel Institute, Carnegie Scholarship Memoirs, 1937, vol. 26, p. 123.

In studying the remarkable yield point in steel it is helpful to ascertain to what extent other metals behave similarly, as the authors have done in the case of molybdenum. Duralumin (annealed) is a prominent example, however, which they do not mention, as it exhibits not one as in iron, but several sudden yields (Fell, loc. cit., Figs. 13 and 14). Also at the same time strain markings may be seen quickly spreading along the metal. A photograph of them on a Duralumin test-piece pulled immediately after solution heat treatment has been given recently and the markings were very indistinct in the same material pulled after ageing. It seems clear that the changes produced on ageing prevented the mass slipping. The propagation of the distortion (sudden yield) as shown by these markings in Duralumin indicates that there is a pretty close connection with the propagation of the distortion (Hartmann lines) at the yield point in iron and soft steel. and hence that the remarkable yields themselves may be very similar. However, aluminium has a face-centred cubic lattice and only one type of slip plane compared with iron, which should result in mass slip being more difficult. In these respects, β-brass is more like iron, but I have unfortunately been unable to prepare a suitable specimen of small enough crystal size to determine its yielding properties (Fell, loc. cit., p. 157). It should have provided a direct check on the yield point in iron.

It may interest the authors to remind them of certain recrystallisation effects. For example, if a section through a Brinell impression in soft steel be examined after heating to produce gross recrystallisation, it will be found that the areas of recrystallisation resemble concentric zones about the indentation, which are quite independent of the Hartmann lines that extend outwards away from the zones. Hartmann lines do not result in that marked recrystallisation which occurs if the applied stress is increased

slightly beyond the yield stress.

The authors also give a curve in Fig. 43 to represent the change in permeability at the yield point, but it is suggested that a kind of double curve representing the permeability of (a) elastically distorted and (b) permanently distorted metal existing there simultaneously would help towards a clearer description of the facts

(e.g., Fell, loc. cit., Fig. 10, p. 140).

The authors refer to the suggestion that the yield point is dependent on the carbon content of the steel, and it might be of interest to them that experiments by myself showed, without any doubt, that the remarkable and sudden yield as seen in iron and steel could occur in the absence of carbon. Hartmann lines were obtained on material previously decarburised in hydrogen, which showed that carbon had nothing to do with them (loc. cit.).

¹ Arrowsmith, Wolfe and Murray, Journal of The Institute of Metals, 1942, vol. 68, Plate XI., Fig. 8.

Mr. T. F. Russell (English Steel Corporation Ltd., Sheffield) wrote: Professor Andrew's new theory to account for the hardening of steel by cold-work has at least one thing in common with all theories so far put forward: it assumes that some change takes place on the slip planes during deformation. Some years ago Rosenhain put forward the theory, based on the work of Beilby, that hard amorphous or vitreous layers were formed on the slip planes during cold-working. For some reason or other, quite incomprehensible to me, most metallurgists blindly followed Rosenhain when he renounced his theory, and now it is generally in disfavour.

Let us see how the new theory varies from that of Rosenhain. For vitreous material to be formed, it is essential that, probably by the combined action of temperature and pressure, the metal must reach the state of fusion. This question was examined quantitatively by me in 1923, when I proved—and the proof has never been refuted—that the potential energy absorbed during cold-working could be accounted for by supposing that there were present numbers of layers a few atoms thick which had been in a state of fusion and then instantly chilled. Professor Andrew now said "... the heat generated along the planes of slip can quite conceivably be sufficient to raise instantaneously the temperature locally to a sufficient degree, not only to promote the α-γ change but also to bring about the solution of carbon. The two effects, due to pressure and increase in temperature, will therefore combine to bring about this transformation." Hence, the only difference in the mechanisms of the processes envisaged by Rosenhain and by the authors is in the instantaneous temperature attained on the plane of slip.

There is, however, one aspect in which Professor Andrew's theory varies from all others. Professor Andrew's can apply only to those metals which have an allotropic change at high temperatures, whereas all other theories are applicable to all metals which workharden, even though they have no allotropic forms. It seems to me that the requirements for the formation of some vitreous phase do not exclude the possibility that some of the allotropic form, when it exists, will be retained when the "fused" layer is almost instantaneously cooled, and from that point of view I started to examine very carefully the evidence put forward by the authors; however, I

soon found myself side-tracked on to other issues.

For example, when referring to the tempering of the quenched 1·2% carbon steel the authors say that "dilatation and thermal heating curves taken after this treatment, Figs. 13 and 14, serve to confirm the contention that oil-quenching conserves a larger quantity of austenite than is obtained after quenching in water." I would suggest that there is no evidence whatever either for or against this contention in either Fig. 13 or Fig. 14. The authors give two reasons for drawing their conclusion. First, the dilatation curves show that the oil-quenched specimen is denser than the water-

¹ T. F. Russell, Journal of The Iron and Steel Institute, 1923, No. I., p. 497.

quenched, and they conclude that this shows that the oil-quenched specimen contains more of the denser constituent austenite. This deduction is fallacious, as the authors seem to have overlooked the fact that oil-quenching is more likely to give the β (cubic)-martensite than the α (tetragonal)-martensite. As β -martensite is denser than α -martensite, no conclusions on the relative amounts of austenite in the water-quenched and oil-quenched specimens can be drawn.

Secondly, the authors claim that the inverse-rate curves, Fig. 14, show that "the evolution of heat over the range 350-570° C. is slightly greater in the oil-quenched state." This calls for two comments. Three years ago I published a detailed study 1 of the interpretation of inverse-rate curves and pointed out that an integration of inverse-rate thermal curves, i.e., any areas obtained from inverse-rate data, do not give a comparison of quantities of heat; they compare times only. Further, if it be supposed for a moment that the inverse-rate curves in Fig. 14 do show that the evolution of heat over the range 350-570° C. is slightly greater in the oilquenched condition, I will explain later why, in my opinion, this evolution of heat is certainly not due to the decomposition of austenite. It is unfortunate that the authors have not given more attention to the paper on inverse-rates referred to above. If they had done so they would have given more careful consideration to their interpretation of the so-called evolution of heat at 120° C. immediately following the alleged absorption of heat at 110° C., for in the paper cited it was shown that a swing-back beyond the datum line was a natural consequence of any absorption of heat over a narrow range of temperature, and the more rapid rise of temperature must not necessarily be considered to be due to an evolution of heat from the test-piece.

The absorption of heat at 110° C. found by the authors is very exceptional. More than fifty years have elapsed since Osmond first published in English his classical paper on inverse-rate curves, which included the heating curves for a quenched carbon steel. During this period about sixteen papers have been published on the evolutions of heat during the heating of tempered steels. The methods used included inverse-rate heating curves, differential heating curves and methods based on calorimetry, and yet, as far as I can ascertain, none of these authors even hinted at any absorption of latent heat round about 100° C. during the heating of a quenched steel. This fact, together with my own experience, makes me look upon this experimental result of the authors with the greatest amount

of scepticism.

Again, in their explanation of transformations, the authors say that the two inflections found on the dilatation curves at 150° C. and 300° C. are probably due to the decomposition of α - and β -

¹ T. F. Russell, Journal of The Iron and Steel Institute, 1939, No. I., p. 147_P.

martensite, respectively. Now, ever since it was first recorded (probably by Maurer in 1908) that, on low-tempering a steel with an austenite-martensite structure, obtained by quenching a highcarbon steel, there was an interval of temperature between the visible commencement of tempering of the martensite and of the austenite, the two-stage process of tempering has been investigated by scores of workers, who have used almost every possible test available to the metallurgist. There is almost unanimity of opinion that the lower-temperature change (from 80° to 120°) is the amartensite to β-martensite change and that the higher-temperature change at about 300° C. is due to the decomposition of austenite both changes being accompanied by an evolution of heat, a contraction in volume, a fall of electrical resistance, &c. It has even been reported that X-ray examination shows that the spectral lines of retained austenite found in quenched carbon steels do not have their intensity reduced after tempering at 200° C., but that they diminish rapidly on tempering at 240-300° C. How, then, can it be reasonably suggested that the evolution of heat over the range 350-570° C. is in any way connected with the decomposition of retained austenite in quenched carbon steels? Is it not reasonable to suppose that if any austenite were present in cold-drawn carbon steel, it too would be decomposed before reaching a temperature of 350° C.—see Fig. 15?

The experimental result recorded in Fig. 15, namely, that a colddrawn carbon steel on heating to 350° C. will, on cooling again, show a change accompanied by an expansion commencing at 150° C... undoubtedly needs experimental confirmation by other means. It cannot be argued that, by analogy with the well-known phenomenon of secondary hardening in high-alloy steel, the change is an austenite --> martensite change. The high-alloy steels show a lowtemperature expansion even on cooling after a second fairly long tempering at temperatures round about 650° C. This is readily explained by the fact that the austenite of some of these highly alloyed steels is extraordinarily stable in ranges of temperature between the austenite ---> pearlite and the austenite ---> martensite change points. The stability of carbon-steel austenite in this range of temperature is insignificantly low when compared with that of the high-alloy steels—a fact well known to those who study isothermal transformations—and for that reason I do not think that the low-temperature expansion shown in Fig. 15 can be due to an

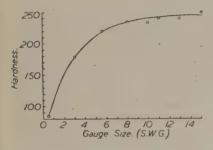
austenite --> martensite change.

The authors themselves admit that the experimental result reported in Fig. 15 and the accompanying secondary hardening are the most convincing proof they put forward that austenite is formed during cold-working, but, whilst admitting, as stated in my first paragraph, the theoretical possibility of the retention of some austenite, as incidental to the vitreous theory, I think that more convincing evidence is required to prove its presence. Finally, I

would remind the authors that no theory of work-hardening can be wholly satisfactory if it does not account for the work-hardening of such non-ferrous metals as have no allotropic changes; this the authors' theory fails to do.

AUTHORS' REPLY.

The Authors replied: We thank Professor Thompson for his constructive criticism. We agree that the hardness of the martensite may be due partly to its strained condition, but wherever martensite exists it must have arisen from an original austenitic structure. Andrew and Fairley 1 pointed out the difference in the hardness of cold-drawn carbonless iron and of a 0.6% carbon steel. The curves obtained are plotted in Figs. D and E. It is seen



2500 2 4 6 8 10 12 14

Gauge Size. (S.W.G.)

Fig. D.—Electrolytic Iron, cold-drawn.

Fig. E.—0.66% Carbon Steel, cold-drawn.

that the maximum hardness of ferrite is of the order of 250 Vickers, whereas with the addition of carbon this may reach a value of 500 or over. Further, the two curves are very different in contour.

In view of the fact that the original hardness of the steel was greater than that produced in the iron drawn to its maximum degree, it is suggested that the sudden increment at approximately 60% reduction must be due to some other factor, which we regard as being the solution of earbon. It is of course difficult, if not impossible, to estimate the exact amount of martensite or austenite formed on cold-drawing, or even to estimate the properties of such structural conglomerates. It is possible that the change in atomic structure may be brought about by rearrangement in the lattice due to mechanical distortion alone; this would agree with the theory propounded by Thompson and Millington some years ago.

Dr. O'Neill opposes the theory because he considers it to be unnecessary. To regard a theory accepted by the majority as

¹ J. H. Andrew and T. Fairley, Report of the Cold-Working Steel Committee, Ironmonger's Research, 1933.

being the last word, and to object to criticism of so-called established hypotheses, particularly when supported by new experimental evidence, is surely unscientific and not conducive to progress.

We made it abundantly clear that our explanation concerns only iron and steel, our purpose being a comparison of the relation between quenched and cold-worked steels. Instead, Dr. O'Neill points out the increase in hardness of certain non-ferrous metals, cold-worked and tempered, as the ground of objection. We do not wish to dispute Dr. O'Neill's quotation on decarburised mild steel for which no reference is given. As far as we are aware, it had been shown definitely by numerous workers that pure iron underwent no secondary hardening on cold-working followed by tempering; instead, a decrease in tensile strength and hardness of the order of 5% at 300° C. was noted. This, coupled with the results obtained on carbon steels, certainly agrees with our view on the solution of carbon during cold-working.

In regard to the question on the distribution of martensite in a cold-drawn steel, we are not in a position to pass any remark. It is extremely unlikely that the distribution would be homogeneous.

No one denies that there are certain differences between coldworked and quenched material. For example, the increment in hardness produced by quenching and similar increments produced by cold-working do not bear the same relation to the increment in tensile strength. Further, cold-working obviously involves severe fragmentation of the crystal units of the material, and certain elastic energy must have been stored at the crystal boundaries as postulated by Heyn ² and shown by others.³ The difference in the limit of proportionality, its response to tempering at 100° C. and fatigue stressing between cold-worked and quenched steel, pointed out by Aitchison, as well as the difference in Meyer value pointed out by Dr. O'Neill, might conceivably be due to this. With regard to X-ray examination, Burger's work cannot be accepted as final. and more recent investigations on this line rather tend to show that, however small it may be, cold-working does after the lattice parameter.

Dr. Jay's verbal contribution is most interesting, and affords considerable confirmation of our views. With regard to his written communication, we thank him for pointing out certain anomalies in the graphs. Dr. Jay is correct in stating that the point c in some cases represents a point 100° C. below the Ac₁ change point. The point c really represents the position in the curve where it departs from the linear form. We have stated that the heat generated on drawing may be sufficient either to age or even soften

Wissenschaften, 1921, p. 121.

¹ H. E. Cleaves and J. G. Thompson, "The Metal 'Iron'," pp. 504-505, Figs. 99 and 101. New York, 1935: McGraw Hill Book Co., Inc.
² E. Heyn, Festschrift der Kaiser Wilhelm Gesellschaft zur Forderung der

³ V. Caglioti and G. Sachs, Zeitschrift für Physik, 1932, vol. 74, p. 647,

the steel, and therefore the low-temperature changes are likely to vary in magnitude. It is agreed that further work on these changes is desirable, but we are confident that our interpretations are correct.

In answer to Dr. Jay's questions on the thermal e.m.f. curves, we believe that the measurement itself indicates the difference in potential between the hardened and soft wires. Whereas the hardened wire may be the same, if the soft wire is treated differently different results will be obtained. It will be seen that the soft wire used for Figs. 22 and 23 had received a long-time sub-critical annealing, and was comparatively free from stress compared with those for Figs. 20 and 21. It is not proposed to measure the area enclosed by the Ac₁ arrest, from the curves; it is obvious that any such attempt would lead to arbitrary values. Personally, we agree with Dr. Jay on the increase of surface contact between disrupted carbide particles and α-iron, thus possibly increasing the rate of reaction at Ac₁.

With respect to the curve in Fig. 15, it has been pointed out that austenite does not appear to decompose on heating to 350° C., but only on cooling from this temperature. Why this is so is still not explained. It is quite true that small amounts of drawing reduction do produce a remarkable effect, but different from that produced by larger amounts. Dr. Desch's criticism is surely illogical; he will agree to the formation of a Beilby layer, which is representative of a temperature approaching the melting point, but he does not approve of a temperature somewhat lower, which will give

rise to the γ form.

Both Dr. O'Neill and Dr. Desch draw comparisons between steels and non-ferrous alloys. Whereas the effect of cold-work with respect to crystal breakdown may be the same, other factors make such a comparison impossible.

It is quite evident that the high tensile test result produced in drawing tungsten requires an explanation, and it is possible that a change peculiar to this metal is produced on cold-working.

We appreciate Dr. Quarrell's contribution on Fig. 14. It is true that if the curves indicated by dotted lines be drawn parallel to that of the unquenched specimen, the evolution of heat over the 350-570° C. range no longer exists. On the other hand, an apparent absorption of heat will be brought out at 380° C. This absorption of heat, cannot be wholly accounted for by the swingback as suggested by Dr. Quarrell, because it will be larger in the oil-quenched steel than in the water-quenched steel, whereas the evolution of heat prior to this swing-back is obviously greater in the latter. Moreover, it is equally unjustified to compare the quenched or even the tempered state with the annealed condition.

We thank Dr. Fell and Mr. Allison for their supporting remarks. Such evidence as they have supplied is not only of great interest and value, but also shows clearly that our theory fits in well with

experimental facts.

We thank Mr. Russell for his critical remarks. Mr. Russell does not exclude the possibility of an allotropic change brought about by temperature and pressure during cold-working, but rather goes further in supporting the view that under such conditions the metal must have reached a state of fusion in layers a few atoms in thickness. So far as we are aware, no amorphous metal has ever

been preserved after cooling from the molten condition.

The answer to Dr. Quarrell's contribution applies to Mr. Russell's query on Figs. 13 and 14. In addition, we would like to point out that specimens of the steel in question quenched both in oil and in iced brine were examined microscopically. The sample quenched in iced brine showed an almost uniform martensitic structure with very little austenite, whereas the oil-quenched specimen consisted of martensite and massive troostite in which austenitic grains could be distinguished. The contention that the oil-quenching conserves a larger quantity of austenite than is obtained after quenching in water is, therefore, not entirely without foundation.

Mr. Russell doubts the existence of an absorption of heat round about 100° C., because of the fact that no previous workers have ever hinted at such a point. Have those previous workers indicated that their experiments were conducted immediately after quenching? Identical results have been obtained in the Department of Metallurgy at Sheffield University by several independent workers on many different occasions, subject to our exact experimental conditions

being fulfilled.

In regard to the $\alpha-\beta$ martensitic transformation, Mr. Russell holds the view that they are two separate phases and that the transformation is completed at 120° C. According to Öhman ¹ and other competent workers, there appeared to be no sharp demarcation between these two phases. The expansion of the c axis of the α lattice from cubic to tetragonal was a function of the carbon content of the steel. On heating a quenched high-carbon steel, the c axis gradually contracted as the carbon separated out, and the axial ratio of the lattice parameter approached unity when most of the carbon was precipitated. The transformation process, therefore, is essentially gradual, and quite different from the view put forward by Mr. Russell. Strictly speaking, no martensite possesses an exact cubic lattice, as the entry of carbon to form martensite results in lattice distortion. Otherwise, can Mr. Russell explain why some martensite should exist as tetragonal and other as cubic?

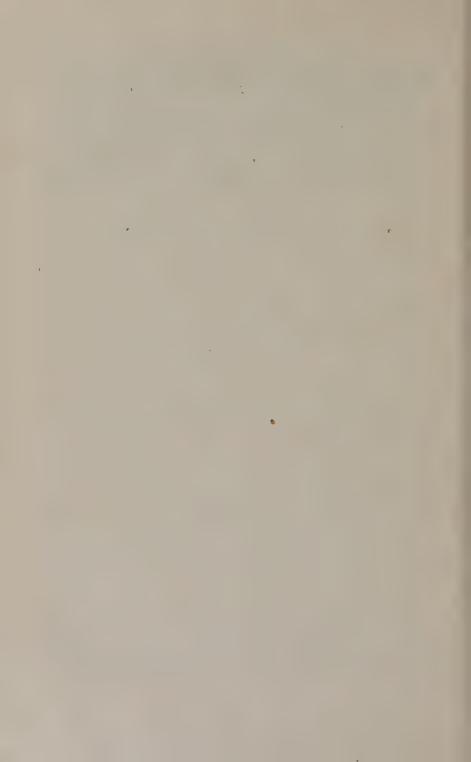
Mr. Russell points out that the higher-temperature change at 300° C. was due to the decomposition of austenite. We think Mr. Russell may have made a mistake in saying that the decomposition of austenite is accompanied by a contraction in volume. Is it not true that austenite is the denser phase? Similarly, Fig. 15 by no means shows that austenite decomposes on heating before

¹ E. Öhman, Journal of The Iron and Steel Institute, 1931, No. I., p. 445.

reaching 350° C., but rather on cooling from that temperature. In order that austenite could be decomposed on heating, a higher temperature would be needed.

Perhaps the increase in length of a cold-drawn steel after tempering at 350° C. needs no more confirmation, and we request Mr. Russell to refer to the papers by Greaves ¹ and by Rees.²

¹ R. H. Greaves, "Gun Wires." Research Department, Woolwich, Report No. 60, 1924. ² S. H. Rees, Journal of The Iron and Steel Institute, 1928, No. II., p. 195.



THIRD REPORT OF THE LIQUID STEEL TEMPERATURE SUB-COMMITTEE 1

OF THE COMMITTEE ON THE HETEROGENEITY OF STEEL INGOTS.²

(Figs. 3 to 6 =Plates XXIII. and XXIV.)

Paper No. 9/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee).

SYNOPSIS.

The Report covers the work carried out in Sheffield during the last two years with the quick-immersion technique for measuring the temperature of liquid steel by means of a platinum thermocouple.

The Report is divided into two Sections. In the first, the Sub-Committee present some general comments on the design of the quick-immersion thermocouple, on temperature distribution and control in the furnace and in the ladle, and on emissivity and optical pyrometry, based on the data presented in more detail in the second Section; in conclusion, an outline of the Sub-Committee's pro-

gramme of research is given.

Section II., by Dr. F. H. Schofield, is an account of recent experimental work carried out with the quick-immersion thermocouple in several steelworks in Sheffield. It is sub-divided into three parts. In Part A, a number of suggested improvements in the mounting of thermocouples for employment in open-hearth, are and high-frequency furnaces, with a few points connected with their use, are described. Part B deals with special applications of the instrument—for example, (a) determining the temperature distribution in large and small are furnaces; (b) the comparison of the thermocouple and an optical pyrometer on an open-hearth furnace, showing that only during the boil does the latter give even approximately the temperature of the steel; (c) the determination, by means of the thermocouple, of the accuracy of two types of optical pyrometer when sighted on a stream of steel, namely, the disappearing-filament pyrometer and a new "colour" pyrometer, in which the inferiority of the latter is clearly established; and (d) measurements in the trough, showing the remarkable constancy in temperature of the outflowing metal during the half-hour required for the casting from a 25-ton ladle. In Part C the position at several works with regard to the exercise of temperature control, on the basis of the thermocouple, is dealt with, showing that a definite routine is now in operation in many of the smaller furnaces, and that good results have already been obtained in some of the larger.

Received May 5, 1941.
A Joint Committee of The Iron and Steel Institute and The British Iron and Steel Federation, reporting to The Iron and Steel Industrial Research Council.

Mr W F Bardgett

INTRODUCTION.

The personnel of the Liquid Steel Temperature Sub-Committee has been changed since their last Report was presented in 1939. It is now as follows:

The United Steel Companies Ltd.

MII. W. El. Dalugou	The Office Steel Companies, Ltd.
Dr. C. H. Desch, F.R.S.	The Iron and Steel Industrial Research
	Council.
Mr. E. W. Eleoek (Chairman)	English Steel Corporation, Ltd.
Mr. C. E. Foster	Foster Instrument Co., Ltd.
Mr. R. A. Hacking	Messrs. Dorman, Long & Co., Ltd. (liaison
<u> </u>	with Blast-Furnace Reactions Research
	Sub-Committee).
Mr. P. Jubb (Secretary) .	Messrs. Thos. Firth and John Brown, Ltd.
Mr. D. Manterfield	Messrs. Steel, Peech and Tozer.
Mr. S. Matthews	The Cambridge Instrument Co., Ltd.
Mr. D. A. Oliver	Messrs. Wm. Jessop & Sons, Ltd.
Mr. R. T. Percival	Sheffield University.
Dr. F. H. Schofield	The National Physical Laboratory.
Mr. A. Stanfield	Messrs. Thos. Firth and John Brown, Ltd.
Mr. W. J. Todd	Messrs. Hadfields, Ltd.
Mr. F. Wakeham	Cambridge Instrument Co., Ltd.

Four meetings have been held during the period under review. At three of these Mr. T. Land (Messrs. Wm. Jessop & Sons, Ltd.) and Mr. E. Ward (Messrs. Thos. Firth and John Brown, Ltd.) and at one meeting Mr. N. H. Bacon (Messrs. Steel, Peech and Tozer) were present by invitation.

In their last Report ¹ the Sub-Committee were able to recommend the so-called "quick-immersion" thermocouple for the general measurement of the temperature of liquid steel in the furnace and elsewhere and to make certain suggestions in relation

to it. Thus it was suggested that:

(1) Users should pool their experience of the new quickimmersion technique with a view to clearing up various undetermined features.

(2) The first aim in using the couple should be the accumulation and analysis of data of temperature conditions in existing practice, with full temperature control as the ultimate objective.

(3) Determinations should be made of the emissivity of a liquid steel, obtained from its apparent temperature as given by an optical pyrometer.

In spite of the abnormal conditions resulting from the war, the quick-immersion pyrometer has been steadily developed and is now widely used.

The present Report is divided into two Sections. The first contains some general comments on the design of the quick-immersion thermocouple, on temperature distribution and control in the

¹ Eighth Report on the Heterogeneity of Steel Ingots, p. 235, Iron and Steel Institute, 1939, Special Report No. 25.

furnace and in the ladle, and on emissivity and optical pyrometry, based on the data presented in more detail in the second Section; an outline of the Sub-Committee's programme of research is also given. Section II., by Dr. F. H. Schofield, is an account of recent experimental work carried out with the quick-immersion thermocouple in several steelworks in Sheffield.

SECTION I.—REVIEW OF THE WORK OF THE SUB-COMMITTEE.

A.—Design of Quick-Immersion Thermocouple. (See Section II., Part A.)

Though the essentials of the instrument remain unchanged, it will be seen that a considerable amount of attention has been paid to detailed improvements in design. The Sub-Committee express no opinion on the relative merits of these improvements, which seem to reflect to some extent the diversity of conditions at the various works. It would appear that the instrument is still undergoing a process of evolution and that it would be premature

at this stage to attempt to stereotype its various forms.

There is, however, one matter to which attention may be drawn, namely, the type of indicator to be employed, since, as explained in Section II., this affects to a considerable degree the design of instrument, particularly that for use in large furnaces. There seem to be two schools of opinion on this matter: According to one, the measurement of temperature should, on grounds of economy and the desirability of enlisting the interest of the furnace staff, be assigned to that staff, who are judged to be capable of reading a millivoltmeter but not of manipulating a potentiometer; according to the second view, the advantages of the potentiometer are so great that it should be used even if this involves the employment

of special staff to take the readings.

It is not proposed to enter into a discussion of this question beyond emphasising the point that the potentiometer is undoubtedly free from the two main sources of error of the millivoltmeter, namely, the effect of changes of temperature on the circuit resistance and secular changes of calibration. The latter can readily be guarded against by occasional check. The former are a source of error which has previously been taken into account in steelworks pyrometric practice by the use of indicators of high internal resistance to swamp the effect. With the new technique of employing the thermocouple in furnaces, involving the traversing by the couple or its leads of a zone of very high temperature some 6 ft. in length, the errors due to changes in circuit resistance may become excessive and impossible of proper rectification by modification in any design of apparatus embodying an available type of portable millivoltmeter. Thus, as will be seen from Section II., an error of 20° C. was traced to this cause in one type of apparatus.

It is suggested that this point should be investigated further with the various types of apparatus now in use. All that is required is that the electrical resistance of the circuit should be observed under various conditions, e.g., before use, while in the furnace, after withdrawal from the furnace and during a period in which successive immersions are made at the highest rate likely to be

adopted in practice.

It may be added that there exists the possibility of a third type of indicator possessing the advantages of the potentiometer with greater simplicity of action. This consists essentially of a combination of mirror-galvanometer, photocell and valve by which the current is automatically adjusted in a circuit, so that the e.m.f. on a fixed resistance in that circuit balances the e.m.f. of the thermocouple. The e.m.f. of the couple is thus expressed in terms of the current given by a milliammeter, the readings being independent of variations of resistance in the couple circuit. The speed of response of the instrument is limited only by that of the milliammeter, the readings of which can, if desired, be recorded in the usual way.

At least two arrangements of this description have reached an advanced stage of development, and it is suggested that consideration should be given to the possibility of applying some such system

to the quick-immersion thermocouple.

B.—Temperature Distribution and Control. (See Section II., Parts B and C.)

In the Furnace.

The ultimate object of measuring liquid steel temperatures is to achieve control of the temperature at which the metal is poured and also that at which each important reaction occurs.

It is clear that full control in this sense can be exercised only in the furnace and that the ideal condition would be that the bath should at all times show a complete uniformity of temperature, readily measurable by a single immersion of the thermocouple. It is also clear that, with existing systems of applying heat, a reasonable degree of uniformity in the charge can only be expected as the result of vigorous stirring, a factor which tends to increase

in importance with the scale of the furnace.

As is well known, stirring occurs as a continuous process in the high-frequency furnace, thus giving an approximation to the ideal condition, of which full advantage is already being taken at several works. In the smaller arc furnaces of the bottom-return type, according to the observations of Messrs. Wm. Jessop & Sons, Ltd., a fair degree of uniformity seems to be attained naturally. As regards the larger arc furnaces, the work summarised in Section II. indicates that the stirring which occurs during the period of boiling tends to promote uniformity, as does also the process known as

rabbling. In the case of the open-hearth furnace, the evidence now adduced, with that previously available, suggests that the bath is much more uniform in temperature during and immediately after boiling than at other stages. The promotion of uniformity

by stirring seems impracticable in this case.

The position with regard to the actual exercise of control appears to be as follows: Full control, on the basis of temperatures given by the quick-immersion thermocouple, is in successful operation in the high-frequency and small are furnaces. Even in the larger are furnaces, ranging in capacity up to 30 tons, the English Steel Corporation, Ltd., have found it possible to schedule limits of temperature desirable at various stages, the temperature being observed under standard conditions after rabbling the bath, and the final reading being checked against observations taken in the ladle. The result of this control has been a marked improvement in "cleanness." In the case of the acid open-hearth furnace, it has been found possible by Jessop's to fix, respectively, minimum and maximum temperatures immediately prior to adding ore and at the "going-on" stage. The temperature at the latter stage is found to affect the cleanness and give an indication as to whether the bath is running "hot," "normal" or "cold" in time to allow adjustments to be made. At the works of Messrs. Thos. Firth and John Brown, Ltd., thermocouple readings are taken in the open-hearth furnace under standard conditions every half hour during the boil and onwards, these readings being used as a guide for furnace control. Messrs. Hadfields, Ltd., find the instrument particularly valuable at the "oreing" and refining stages in the acid process, and generally for control and investigation in all types of furnace.

While a promising start has thus been made in the temperature control of furnaces, including those of the largest size, it is clear that much remains to be done before any approach to finality can be reached in this difficult matter. Even the precise scope of the problem cannot be defined without a knowledge of the temperature distribution prevailing in different types of furnace and at different stages of operation. It would appear therefore that, sooner or later, it will become desirable to carry out appropriate threedimensional explorations of specimen furnaces. Such explorations could probably be made satisfactorily with the quick-immersion thermocouple or, if necessary, with an alternative type of instrument suggested in (1) below. They might be expected to reveal, among other things, whether a single reading of the thermocouple, taken at a fixed position and under definite conditions, would give a "representative" temperature, that is, the true mean temperature of the bath or one differing from it by a fixed amount. Should this turn out to be the case, the problem of control would obviously be much simplified.

As the desideratum of control on this basis could be established

generally only by exhaustive and troublesome explorations, it seems worth while to consider whether a simple overall test could be devised as to the representative character of readings taken at an important stage or stages. For example, such tests might be applied to the readings taken just before the tapping of an openhearth furnace by means of a thermocouple immersed at the centre of the furnace to a certain depth (say, 10-12 in.). In this case it would be desirable in the first place to ascertain the vertical gradient of temperature at the centre of the bath, for this would determine the accuracy with which it would be necessary to reproduce the depth of immersion. The tapping temperature could be linked with observations taken immediately afterwards in the launder, or ladle, or both. In the former, a fair mean temperature could probably be obtained from four or five readings equally spaced during the time of flow; while in the ladle the temperature should certainly be more uniform than in the furnace. As described in Section II., observations of this kind have already been taken on arc furnaces by the English Steel Corporation and The United Steel Companies, but it is recommended that they should be greatly extended and applied also to the open-hearth furnace with a view to a more certain control of tapping temperatures.

Another stage meriting special investigation is that during or immediately after boiling. If, as is suspected, the temperature at this stage is nearly uniform for all types of furnace, it would be worth while to undertake first the special explorations required

to establish this as a fact.

While it is hoped that complete temperature control may prove to be possible on the basis of single readings of the quick-immersion thermocouple, it is as well to remember that this may prove difficult of attainment, at any rate in the larger furnaces. Consequently it may not be out of place to adumbrate the possibility of other methods which may ultimately be worth considering as alternative, or supplementary, to the use of the thermocouple. For example:

(1) A photocell pyrometer might be devised, which, by virtue of its rapid response, would enable temperatures to be recorded for a considerable sweep of the instrument on each insertion. It is contemplated that such an instrument might consist of a photocell sighted at short range into a silica tube, the whole being mounted in a similar way to that adopted for

the quick-immersion thermocouple.

(2) Use might be made of comparative measurements of the electrical resistance of part of the bath as a means of getting the average temperature. Thus, if simultaneous measurements of temperature by thermocouple and of resistance were made when the bath was reasonably uniform, e.g., during boiling, and the coefficient of electrical resistance were known, a second measurement of resistance at tapping might give

an average temperature, at any rate for certain classes of steel.

With regard to (2), it may be added that the measurements of resistance, apart from their use for thermometric purposes, might be of interest in themselves, and it might even be possible to measure the resistivity, as distinct from the relative resistance, of the steel while still in the furnace.

In the Ladle.

The possibility of control in the ladle, if the charge should be too hot, should not be overlooked. As a preliminary it would be necessary to determine the rate of cooling for various types of ladle and depths of charge. This could probably be done by observations on the ladle itself, coupled perhaps with readings taken in the

launder and the trough.

The question of distribution in the ladle also seems worthy of investigation if only for the purpose of throwing light on the constancy of temperature of the outflowing metal. A striking example of this is quoted in Section II. In this case the trough readings taken during the 34 min. required for the casting of eight 3-ton ingots from a 25-ton ladle showed no appreciable variation in temperature.

C.—Emissivity and Optical Pyrometry. (See Section II., Part B.)

An important investigation has been carried out by Hadfields, concerned mainly with the emissivity and optical pyrometry of liquid steel, in which the quick-immersion thermocouple played an important part as the standard used for temperature readings. This work has been fully described elsewhere and is briefly dealt with in Section II. Since it includes what appears to be the first independent test of a new type of optical pyrometer, for which great advantages over existing types are claimed in the measurement of liquid steel temperatures, it may be opportune to explain the general significance of this test.

Test of New Colour Pyrometer.

The readings of all radiation pyrometers, of whatever type, are referred to a universal standard known as the black-body radiator, which consists of any complete enclosure with its internal surface at a uniform temperature. If radiation is allowed to escape through a very small hole in such an enclosure, the amount of energy in any wavelength, per unit area of the hole, is found to depend solely on the temperature of the internal surface, and not on the shape and material of that surface. Further, when the temperature of such an enclosure is changed the amount of energy emitted in each

¹ W. J. Todd, Metal Treatment, 1939-40, vol. 5, p. 17].

wavelength is altered according to a certain law. These characteristics have been used for two systems of optical pyrometry—the brightness and the colour systems—depending on two properties of the eye, namely, its capacity to judge (a) the equality of brightness of two objects when they have the same or nearly the same colour, and (b) the identity of colour when they have the same

or nearly the same brightness.

For a number of reasons which cannot be detailed here, the former system is generally to be preferred. For instance, the near identity of colour demanded by (a) can readily be obtained by the simple expedient of viewing both objects through a coloured screen, generally red, having a narrow band of transmission, whereas a separate adjustment is necessary at each temperature to obtain the approximate equality in brightness demanded by (b). Further, eyes may differ considerably in colour perception, as is shown by the phenomenon of colour blindness, so that the system (b) may,

in some cases, be rendered uncertain if not unworkable.

Nevertheless, it is possible to imagine conditions in which the balance of advantage would lie with the colour system. To take an extreme case, if all hot objects were "grey bodies," that is to say, if they emitted in every wavelength an amount of energy bearing a constant proportion to the corresponding amounts emitted by a black body at the same temperature, then it is clear that the colour temperatures of all objects would be identical with their true temperatures, for the colour of an object is determined solely by the proportions in which its component colours are mixed. If, however, different objects, while each showing a constant emissivity throughout the spectrum as just imagined, were characterised by different emissivities, then their brightness temperatures would differ. For example, if one steel had a constant emissivity of 0.5 and another of $0.\overline{3}$, then, for a true temperature of 1600° C., their respective brightness temperatures for a wavelength of, say, 0.65 μ would be 105° C. and 175° C. too low. If in this case the common practice of assuming an emissivity of 0.4 were applied, the uncertainty would be + 35° C. On the other hand, the colour temperatures of the two steels would agree exactly with their true temperatures, so that they would show no uncertainty.

It is hardly necessary to point out that the state of things imagined above is rare, if not unknown; otherwise the colour pyrometer, in spite of its complications, would be in a greater demand for measurements made other than under black-body

conditions.

The designer of the new colour pyrometer seems to have acted on the assumption that, in the case of steels, the colour principle would have an advantage over the brightness principle of the kind, if not of the degree, indicated in the example above. It is true that he recognised that steel is selective in radiation (*i.e.*, it shows a departure from "greyness"), for his instrument incorporates a screen designed to correct blue predominance, which would, of course, make the colour temperature higher than the true temperature. What apparently was not envisaged was that the uncertainties due to varying selectivity might outweigh those due to the variations in emissivity in a single (red) wavelength such as is used in existing brightness pyrometers. The test mentioned above has, in effect, shown that this is the case, with the result that the new colour pyrometer is found to be less reliable in measuring liquid steel temperatures than the present disappearing-filament instrument.

The new pyrometer was also designed to give brightness temperatures on the basis of a combination of two wave-bands, instead of one wave-band as in the disappearing-filament pyrometer, but here again the advantage is found to lie with the latter instrument.

Emissivities of Steels.

The investigation referred to in the previous Part has also shown the surprising range of radiation characteristics of steels of differing compositions. The accumulation of further data on this subject might turn out to be of considerable interest. It is suggested that where the apparent temperature is read by the optical pyrometer as a matter of routine, the question should be considered of recording the corresponding temperature by the immersion couple so as to obtain the emissivity, and that the emissivity might also be determined, on occasion, for wavelengths in the green and blue, as well as red, by fitting the appropriate filters to a disappearing-filament pyrometer.

If the optical reading is taken on the launder stream, the thermocouple would naturally be applied there; if on the stream from the ladle, the appropriate place for the couple would be in the trough, should one be employed, or otherwise in the ladle or the launder

stream, the necessary correction for cooling being applied.

D.—Programme of Research.

The various suggestions for further work which have been made, either above in Section I. of this Report or below in Section II., may now be set out as follows:

Design and Characteristics of Instrument.

(1) Measurement of the circuit resistance under various conditions to determine safeguards for the use of the millivoltmeter.

(2) Test of indicating systems alternative to the milli-

voltmeter and potentiometer.

(3) Miscellaneous tests, e.g., on the carbon end block, the best diameter of thermocouple wire, the rate of thermocouple depreciation.

Temperature Distribution and Control.

(4) Explorations of temperature in different types of furnace and at different stages, starting with the boiling or "going-on" stages.

(5) Determination of the best conditions for observing the tapping temperature. Correlation of this temperature with

the mean temperature in the launder and ladle.

(6) Investigation of the temperature distribution in the

ladle.

(7) Determination of the rate of cooling of the charge in the ladle by direct observation or by comparison of the launder and trough temperatures.

Emissivity of Steel.

(8) Routine determinations of emissivity.

(9) Special determinations of emissivity in more than one wavelength.

The whole of this programme apart from items (2) and (9) involves observations on steel while in process of production. Item (4) would call for extensive observations, which it may not be feasible to undertake rapidly in present circumstances. The remaining items should cause little or no interference with production, but would make considerable demands on the time of staff.

The programme has been drawn up on the assumption that the work would be undertaken, as before, by the firms represented on the Sub-Committee. If it meets with their general approval, the Sub-Committee would be prepared to advise on the allocation of the work with a view to securing the most effective co-operation.

E.—Acknowledgments.

The Sub-Committee desire to acknowledge their indebtedness to the firms mentioned in Section II. for supplying the material on which it is based. They would also express their thanks to Dr. F. H. Schofield for drafting this Report.

SECTION II.—RECENT WORK WITH THE QUICK-IMMERSION THERMOCOUPLE IN THE STEELWORKS OF SHEFFIELD.

By F. H. SCHOFIELD, B.A., D.Sc. (Physics Department, National Physical Laboratory, Teddington, Middlesex).

Introduction.

In the two years which have elapsed since the publication of the Eighth Report on the Heterogeneity of Steel Ingots, 1 containing 1 Iron and Steel Institute, 1939, Special Report No. 25. a full description of the so-called quick-immersion thermocouple, a considerable amount of work has been carried out with this instrument in the steelworks of Sheffield and the neighbourhood.

It may be recalled that essentially the instrument consists of a platinum thermocouple, lightly sheathed in silica, which can be plunged into liquid steel so as to give a reading in a few seconds and be withdrawn intact, and that different forms of mounting were adopted according as the instrument was to be used in the furnace, launder, ladle or trough. The most important use of the instrument is in the furnace, and here it is particularly desirable that the temperature readings should be capable of being taken in the centre of the bath. Consequently for the open-hearth furnace a pipe some 14 ft. in length was employed for enclosing the couple, as shown in Fig. 1, which illustrates one type of mounting.

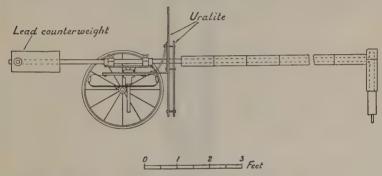


Fig. 1.—Quick-Immersion Thermocouple Mounted on a Trolley.

The part of the pipe to be inserted into the furnace was covered with blocks of "Economite"—a light diatomaceous product—as was also the top part of the extension piece attached at right angles to the end of the pipe. The lower end of the extension piece, the details of which are important, is shown in Fig. 2. The heavy steel end was covered with a block of "Fosalsil"—a denser diatomaceous product—which will withstand a number of successive immersions in steel and slag and also the corrosive action of slag, even of most basic varieties.

The thermocouple had its hot end insulated with twin-bore silica, except for a certain length of bare wire terminating in the junction, and it was contained in a silica tube, which in turn was protected by a thin-walled steel tube. The object of the latter was to ensure, if possible, that the silica tube did not come into contact with the slag while being immersed in the bath, though it was pointed out that it was by no means certain that this precaution was necessary. The silica tube has to be changed after each immersion in slag, a comparatively easy and cheap replacement.

A description was also given of an alternative design similar to the above but arranged for operation by the furnace charger, as well as designs suitable for the launder, ladle and trough. For

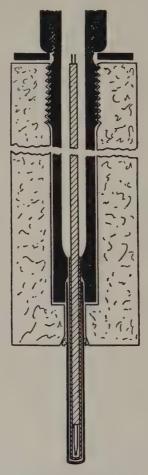


Fig. 2.—End of Apparatus to be Immersed in Steel.

full details of these several designs reference should be made to the Report mentioned (p. 239).

While the instrument in its different forms gave thoroughly satisfactory results, it was recognised that a considerable amount of experience would be necessary before the best could be obtained

from the new technique of the quick-immersion use of a platinum thermocouple, and that, no doubt, various improvements in design would emerge. In this connection a few special problems were indicated—for example, the question of retaining the steel sheath above mentioned, the number of immersions which could safely be allowed before contamination of the couple necessitated the cutting off of 2 or 3 in. from the hot end, and the most suitable gauge of wire for the couple, having regard to the cost of wastage from contamination and the need for adequate mechanical strength.

The work now to be summarised has dealt with a number of points of this description as well as suggested improvements in design. It also covers examples of the uses to which the instrument has been put and the possibility of control to be based on it. The subject has been divided into three parts: A.—Design and Characteristics of the Instrument; B.—Results Obtained; C.—

Possibility of Control.

A.—Design and Characteristics of the Instrument.

In essentials the instrument remains unchanged, but a number of modifications have been made with a view to rendering it more readily operable. Examples of these are given below, arranged according to the use to which the instrument is to be put. It is not possible in the space available to give full details of the individual designs, for particulars of which application should be made to the firms concerned.

In addition to the matters just mentioned, some general questions relating to the use of the quick-immersion thermocouple are dealt

with in the following.

Apparatus for Large Furnaces (Open-Hearth and Arc).

Of the two designs originally described, that intended for operation by the furnace charger has been discontinued, as has also the use of the thin steel sheath covering the silica tube (Fig. 2). The reason for the latter decision is that, in the absence of the steel sheath, the silica tube is found to perform its function of protecting the couple for a single immersion in steel both in acid and in basic furnaces—in fact, two immersions can occasionally be obtained in a basic slag.

In all the designs employed in the works having representatives on the Sub-Committee the arrangement of the silica insulation and the silica sheath, on which the speed of response of the instrument primarily depends, have been retained. The other outstanding features of these designs are tabulated in Table I. The following

comments may be added.

End Block (Table I., Column 3).—In the original design the silica sheath was wedged into a block of "Fosalsil," $3 \times 3 \times 9$ in., which served to protect the steel end piece from contact with the 1942—i

TABLE I.—Modified Designs of the Quick-Immersion Thermocouple for Use in Large Furnaces.

	Insulation,	3	Economite.	None.		Economite.		Cement.	
Main Tube.	Dimensions.		17 ft. × 14 in. × 11 in.	15 ft. $\times 1\frac{5}{8}$ in. $\times \frac{5}{32}$ in. 14 ft. $\times 1$ in. $\times \frac{1}{8}$ in.	6	15 ft. \times 18 m. $\times_{\frac{1}{16}}$ m.		12 ft. $\times \frac{11}{10}$ in. $\times \frac{1}{9}$ in.	11 ft. \times 1 in. \times $\frac{1}{8}$ in.
	Material.		Steel.	20/25 nickel-	chromium steel,	Steel.	r.	Steel.	20/25 nickel- chromium steel.
Thermocouple.	Cold Junctions.	Operated by trolley.	H	ં ં	+	- -	Operated by hand.	0.	°
Thermo	Wire Dia.	Operat	0.5	0 5 5 5	1		Opera	(0.5) (0.3)	0.5
	Indicator.	ř	M.	e. e.	,	W.		P.	M.
	End Block,	5	Fosalsil.	66		• • •		Fosalsil.	Non-pareil, Carbon,
	Furnace.	•	O.H.	O.H. Arc.	,	О.Н.		O.H.	Arc.
	Works.	i	H	FB	į	US(s)		7	US(c)

Contractions used and notes:

Ltd.; J = Messrs. Wm. Jessop & Sons, Ltd.; US = The United Steel Companies, Ltd.; (c) = Messrs. S. For & Co., Ltd., in conjunction with Central Research Department; (s) = Messrs. Steel, Peech and Tozer.= Messrs. Hadfields, Ltd.; FB = Messrs. Thos. Firth and John Brown, Ltd.; ESC = English Steel Corporation,

2: O.H. = open-hearth.

Col. 4: P. = potentiometer. M. = millivoltmeter.

Col. 5: Jessop's employ 0.5-mm. wire in the open-hearth pyrometer and 0.3-mm. wire in all other apparatus.

Col. 6 refers to position of junction between thermocouple wires and compensating leads: 0. = outside furnace;

I = in

head of pyrometer, i.e., inside furnace.

Col. 8: Figures are the length between perpendiculars, outer diameter, and wall thickness, respectively.

liquid steel and slag. It will be seen that this practice has been followed in five cases. The method of attachment of the block by screwing it to the end piece (see Fig. 2) has also been retained, except in the case of J where the block, which is only $4\frac{1}{2}$ in. deep, has been attached by a push fit (see right-hand side of Fig. 5). Incidentally, it may be remarked that the length of block is governed by the depth of slag and the desired length of immersion in the steel, and that the block, as manufactured, has a standard length of 9 in.

With regard to the remainder of column 3, it will be seen that the US(c) works have used the "Non-pareil" block made by Messrs. Newalls, Ltd., which is a diatomaceous product similar to the Fosalsil of Moler Products, Ltd., and have also used a carbon The latter is a particularly interesting development. The block is turned down from waste electrode material. It has the property of not being wetted by either acid or basic slags and has an exceptionally long life. Thus, one block has had 33 immersions (30 basic and 3 acid) without noticeable deterioration. graph of this block after 23 immersions in basic slag is shown in Fig. 3, which also illustrates the fortunate fact that, on cooling down, the slag and silica sheath (which is cemented in over a few turns of asbestos cord) drop off of their own accord, leaving the block free for the insertion of another silica sheath. A further advantage claimed for the carbon block is that its screw thread is stronger than that in the diatomaceous material. On the other hand, the high density and thermal conductivity of the carbon may be disadvantageous in some respects.

Indicator, Thermocouple and Leads, Main Tube (Table I., Columns 4 to 9).—These details of design are inter-related and depend to a considerable extent on whether the apparatus is intended to be used with a millivoltmeter or a potentiometer. For the former instrument, it is essential that the circuit resistance should remain sensibly constant, and this, with long wires traversing the high-temperature zone, requires careful attention to design. For example, the use of 0·3-mm. couple wire for the whole length of the hot region could not be tolerated with a millivoltmeter, for the resistance of the couple would be of the order of 6 to 8 ohms and the changes of this resistance with varying temperature would produce considerable errors on an instrument of 200 to 300 ohms resistance. In the case of 0·3-mm. wire, therefore, a potentiometer

Again, other things being equal, the temperature actually attained by the wires obviously depends on the dimensions of the main tube and its insulation, and on whether the apparatus is used for single readings at wide intervals or a rapid succession of readings. For example, the instrument FB has its main tube covered with $1\frac{1}{2}$ in. of the highly insulating material Economite, so that the temperature rise of the tube for each insertion is not great, but the

should be used.

effect tends to be cumulative, and it was found that, after 4 or 5 immersions made within an hour, the tube had risen to a temperature of the order of 300° C. In this case, the couple of 0.5-mm. wires extended through the hot region, and it was observed that the error in the reading of a millivoltmeter of 300 ohms resistance after 1 hr. amounted to some 20° C. On the other hand, a bare tube, as in the ESC instrument, though it may be red-hot on removal from the furnace, may cool so rapidly as to give little cumulative effect in readings 15 min. apart.

If the millivoltmeter is to continue to be used, further experiment seems necessary to arrive at the best design of apparatus and to

define more exactly its safe conditions of use.

With regard to column 6 it will be noted that in every example the precaution is taken of using compensating leads to transfer the cold junction to the indicator. Should this latter be a millivoltmeter, a further obvious precaution in view of the wide variations of air temperature near a furnace, is to employ one of the well-known devices for automatic cold-junction compensation. Such compensation is not so readily applied to a potentiometer, but if the instrument is of the slide-wire type a movable index may be used to make the necessary cold-junction correction. A device of

this kind is employed by Messrs. Hadfields, Ltd.

The following comments may be added on the individual designs: H follows the original design with, however, some special features. For example, the great length (17 ft.) of the main tube, which is a hydraulic pipe, gives good control and obviates the necessity of a protection shield for the operator. In view of the comparatively low resistance (300 ohms) of the portable millivoltmeters available, special attention is given to the design of the thermocouple and its compensating leads, the total resistance of which amounts to 1.5 ohms. A considerable rise in the temperature of the thermocouple must take place in such a circuit before an excessive error arises in the indicated temperature. The thermocouple unit, contained in the upright tube, is readily removable, a single screw serving to fix it and make connection to the terminal plates of the compensating leads. Correct assembly of the unit is obtained by means of a special holder and gauge.

FB also follows the original design closely, differing mainly from it in that the couple extends to the part of the apparatus

outside the furnace.

In the case of ESC, a bare tube of heat-resisting steel (20/25 nickel-chromium) is used for the main part of the apparatus. The complete instrument, which is shown in Fig. 4, weighs 80 lb., of which the tube assembly accounts for 20 lb. Incidentally, it may be pointed out that the end block in Fig. 4 shows the degree of erosion to be expected after some 10 immersions in a medium-basic slag. For very erosive slags, the device of coating the block with a wash of alumina, which was mentioned in the last Report, adds con-

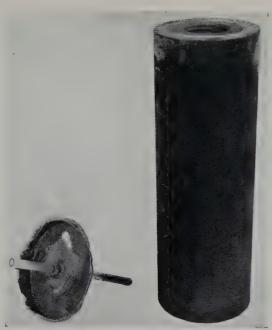


Fig. 3.—Right: Carbon End Block after twenty-three immersions in basic slag. Left: On cooling down, the slag and silica sheath drop off freely.



Fig. 4.—Complete Apparatus; bare tube of heat-resisting steel (20/25 nickel-chromium).

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Fig. 5.—End of Apparatus; right, used at works J (Table I.); left, for smaller arc furnaces.



Fig. 6.—Light-Weight Apparatus for hand manipulation.

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siderably to its life, or the carbon block described above may be used.

J is a light apparatus weighing 13 lb., having a fairly short main tube insulated towards its hot end with a special cement consisting of 49% of Fosalsil plastic compound, 49% of crushed firebrick (8-mesh) and 2% of sodium silicate. This is applied to the tube, which has been loosely wound with a spiral of iron wire, and forms an adherent, easily reparable covering. The end of this apparatus is shown on the right-hand side of Fig. 5.

US(c) has a heat-resisting tube with a light asbestos and cement

covering. Its total weight is 25 lb.

Insertion by Trolley or Hand (Table I.).—The first four instruments form self-contained units complete with trolley. The pipe can be rotated so that, with the end piece horizontal, it can be inserted through a low, or partially opened, doorway. With its radiation shield and great length, this type obviously affords a high degree of protection to the operator.

The other two instruments are intended to be transported by hand, requiring an independent support for insertion into the furnace. Thus, they may be slid over rollers attached to a separate stand, or over a bar in the furnace mouth as shown in Fig. 6. For any sliding motion, a completely bare tube as in Fig. 4 has obvious

advantages.

The decision as to whether to adopt the trolley or the hand type of apparatus depends on a number of factors such as the size and type of furnace, the storage space available, and the size and condition of the floor in front of the furnace.

Apparatus for Small Furnaces (Arc and High-Frequency).

For the smaller furnaces, the designs at the several works are considerably simpler, as will be seen from the following examples.

On the left-hand side of Fig. 5 the end of an apparatus for smaller are furnaces is shown. In this case, the main tube consists of $\frac{1}{4}$ -in. gas pipe and is unlagged. The bend shown is secured by a small wire nail driven between it and the pipe, the gap being filled with aluminous cement, while the Fosalsil block is attached by a push fit to the other end of the bend. This extremely simple

design lends itself to ease of assembly and dismantling.

Fig. 7 shows a design for high-frequency furnaces. The overall length is about 5 ft., and attention may be drawn to the following points. The platinum couple extends to the full length of the apparatus and, when wire has to be cut off from the hot end of the couple, the sliding tube shown is pushed forward by the requisite amount after loosening the set screw. This minimises the strain on the thin couple wire (0·3 mm. in dia.) and ensures that the cold junction never gets too close to the hot region. Further, since only the silica tube has now to be inserted into the steel, it is con-

venient to use the chuck mount shown, which greatly facilitates the changing of tubes.

Apparatus for Ladle, Trough and Launder.

The apparatus for use in the ladle or the trough calls for no detailed comment. Since slag is present in the ladle an end block must be used and the instrument may be in the original form described, with or without some of the modifications indicated above. In the trough, the simplest apparatus suffices, such as that shown in Fig. 7.

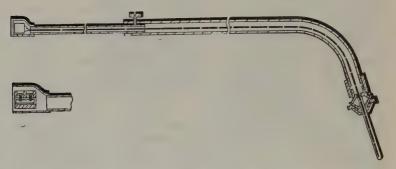


Fig. 7.—End of Apparatus for Use in a Small Furnace or Trough.

In the launder, the original proposal was to use a thick-walled silica tube to be inserted in the stream when inclined at an angle. Such a tube tends to bend, owing to the force of the stream, before a reading can be obtained, and it is thought that this may give rise to error. The National Physical Laboratory is now investigating the possibility of improving the design.

General Questions relating to the Quick-Immersion Thermocouple.

(a) Best Diameter of Wire for Platinum Thermocouple.—Two diameters of wire, 0.5 and 0.3 mm., were employed in the original work, and it was pointed out that, if the latter could be used, the cost of replacement would be little more than one-third of that for the larger diameter. On the other hand, the mechanical strength of the smaller-diameter wire would be very much less. The ideal diameter would obviously be one with which failure due to mechanical breakdown in handling, &c., would be as likely to occur on the average as that due to contamination,

A decision in this matter is affected to a considerable extent by the length of the couple. In the original work a short length of couple and long compensating leads were used. If, as in most of the designs summarised in Table I., the platinum wires are carried to the colder end of the apparatus, including passage round the bend, it is obvious that much greater strain would be placed on the wires.

The matter seems to be one on which further comparative tests are desirable.

(b) Frequency of Renewal of Platinum Thermocouple.—The evidence adduced in the last Report suggested that almost certainly 10 immersions of the 0.5-mm. couple, of average duration of 15 sec., and possibly 20 or more immersions would be allowed in an openhearth without appreciable deterioration occurring.

Messrs. Thos. Firth and John Brown, Ltd., have now supplied

the additional data bearing on this point recorded in Table II.

Table II.—Deterioration of Thermocouples with Use.

Furnace.			Total Time of Immersion.	Error against Un- used Couple.
High-frequency Siemens	:	•	168 sec. 297 ,, 218 ,,	4° C. low 5° C. low 1° C. high
,, • •	•	•	431 "	15° C. low

The details of the first result shown in Table II. are given in Table III.

Table III.—Details of First Test Result recorded in Table II.

	1	1		
Immersion Number.	Time per Immersion. Sec.	Total Immersion Time. Sec.	Couple A. ° C.	Check Couple B.
1	10	10	1620	
2	. 8	18	1540	
3	10	28	1525	
4	10	38	1585	
5	14	52	1625	1624
6	10	62	1670	•••
7	9	71	1610	
8	9	80	1490	
9	7	87	1555	***
10	16	103	1635	1636
îĭ	9	112	1660	
$\hat{1}\hat{2}$	10	122	1630	
îã	1 îŏ	132	1640	
14	ii	143	1670	
15	10	153	1637	
16	15	168	1568	1572
17	16		1580 *	1581
1.1	10	***	1990	1001

^{*} After couple A had been cut back $2\frac{1}{2}$ in.

Couple A was tested after the sixteenth immersion when apparently reading 4° C. low, and showed signs of contamination, i.e., small parasitic e.m.f.'s were noted at the hot junction and

extending over almost the whole of the 3 in. which had projected from the diatomite. The test was carried out at a temperature of approximately 1400° C. The wire was then cut back for $2\frac{1}{2}$ in. and a new junction made, and, as shown in immersion No. 17, the couple agreed with couple B to within 1° C.

The conclusion is that, while it is difficult to determine the rate of deterioration of a thermocouple with immersion time, a maximum discrepancy of 5° C. may be expected after 200–250 sec.

or about 15 immersions of normal duration.

Messrs. Wm. Jessop & Sons, Ltd., have carried out tests on the constancy of their 0·3-mm. thermocouples by comparison with a standard couple in a platinum-wound furnace at 1400° C. Their procedure with regard to renewal of the wire is to scrap the hot end of the couple when it shows signs of becoming brittle. Under these conditions it is found that the couple never reads high, nor does it read low by more than 10° C. Consequently the potentiometer is set to read 5° C. high, so that values can be relied on to an accuracy of \pm 5° C. The following figures, taken at random from the record of couples used for from 20 to 30 immersions a day in high-frequency furnaces show the errors likely to be encountered. In each case the two readings indicate the values for immersions of 6 in. and 2 in., respectively :

Immersion—			Imme	rsion
	6 in.	2 in.	6 in.	2 in.
(1)	1° C. low	7° C. low	(4) 1° C. low	6° C. low
(2)	3° C. "	7° C. ,,	(5) 3° C. ,,	***
(3)	0° C. "	9° C. "	(6) 1° C. "	2° C. "

(c) Life of Fosalsil End Blocks.—Two alternatives to the Fosalsil end blocks have been referred to above, but the blocks continue to be in frequent use. At Messrs. Thos. Firth and John Brown, Ltd., the life of a block in the acid open-hearth furnace has been found to be 15 immersions. This figure may be exceeded in the high-frequency furnace (acid), in which the slag can be moved to one side when immersing. Immersions made in cool metal, however, tend to reduce this number, owing to damage or wear caused by the removal of the additional slag or metal adhering to the block.

B.—Results Obtained.

In the following, examples are given of the application of the quick-immersion thermocouple to a number of special problems.

Temperature Distribution in Large Arc Furnaces.

The United Steel Companies, Ltd., give some particulars relating to the vertical distribution of temperature at the centre of a 10-ton electric arc furnace. The data are plotted in Fig. 8, which shows the difference in temperature at a depth of 1-2 in. as com-

pared with that at a depth of 6-7 in., from the time of melting onwards.

It will be seen (a) that when the bath is coming to the boil, the temperature is markedly hotter at the smaller depth; (b) that this gradient disappears at the boiling period, during the whole of which the temperature remains uniform; and (c) that when the reducing slag is added, a reversed gradient appears, which diminishes as heating continues, finally reversing again and assuming a constant value of $+20^{\circ}$ C. in the final stages.

It further appeared that the gradient is considerably reduced

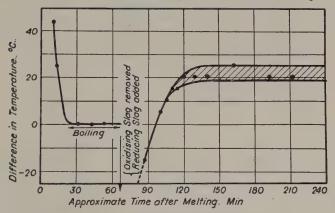


Fig. 8.—Difference between Temperatures at Depths of 6-7 in. and 1-2 in. from Melting to Tapping. 10-ton electric arc furnace.

by rabbling; for example, readings taken 20 min. after rabbling showed the temperature at the smaller immersion to be higher by 25° C., while 4 min. after rabbling the difference was only 5° C.

The English Steel Corporation, Ltd., have also contributed data as to temperature distribution in the large arc furnaces of the Vickers Works. The normal procedure for measurements in such furnaces is to rabble the bath with the power off and electrodes raised and to immerse the couple in the centre of the bath to a depth of 9 or 10 in. The data in Table IV. were obtained with the thermocouple at full immersion and after it had been raised by 4 to 6 in.

These results agree with the observation as to the smallness of the vertical gradient at the centre of a 10-ton furnace after rabbling.

The United Steel Companies, Ltd., have also compared the temperatures at different depths in the centre of a furnace, obtained without rabbling and immediately before tapping, with the temperatures as subsequently read in the ladle. These are summarised in Table V.

If it is assumed that the steel in the ladle is at a uniform tem-

perature, which is more likely to be the case than with the steel in the furnace, it is seen that the reading obtained in the centre of the bath at a depth of 7 in. would be less than the mean temperature of the bath. This further emphasises the importance of rabbling if the attempt is to be made to get the mean temperature from a single reading.

Table IV.—Temperature Distribution in Large Arc Furnaces.

English Steel Corporation, Ltd.

Charge No.	Capacity of Furnace.	Condition of Bath.	Depth of Immersion. In.	Temp.	Temp. Difference. ° C.
1	10 tons	During boiling down.	10	1599 1602	} 3
1	,,	93 93 ' 99	10 5	1602 1610	} 8
2	30 tons	29 29 29	10 6	1604 1609	} 5
3	2>	99 29 39 .	10 4	1587 1592	} 5
3	99	. 99 99 99	10 4	1614 1612	} 2
3	99	During white slag.	10 4	1598 1598	} 0
3	27	Prior to addition.	10 4	1605 1607	} 2
3	>>	Prior to tapping.	10	1604 1604	} 0

Table V.—Comparison of the Temperature in an Arc Furnace and in the Ladle.

The United Steel Companies, Ltd.

	Time between	Ва	th.	Ladle Reading		
Cast No.	Ladle Readings. Min.	Depth of Immersion. In.	Temp. °C.	at 9 to 11 in. Immersion. °C.	Temp. Difference. ° C.	
1 2 3 4 5 6	4 5 4 5 4 5	7 2 3 3 3 2	1605 1630 1615 1595 1600 1645	1615 1610 1590 1580 1570 1630	$ \begin{array}{r} -10 \\ +20 \\ +25 \\ +15 \\ +30 \\ +15 \end{array} $	

Temperature Distribution in Small Arc Furnaces (30-cwt. to 3-ton).

Messrs. Wm. Jessop & Sons, Ltd., give details of both vertical and horizontal distribution in two furnaces of the three-phase bottom-return type (Electrometals). The vertical distribution at the centre of a 3-ton furnace with the electrodes raised and 17 min. after rabbling was found to be as follows:

3-Ton Arc Furnace, Vertical Temperature Distribution.

Depth of immersion. In. . 3 6 9

Temperature. ° C. . . 1491 1484 1485

The details of the horizontal distribution observed on two 30-cwt. furnaces with electrodes raised, $\frac{1}{4}$ hr. before tapping and without special rabbling, are listed below:

30-Cwt. Arc Furnace. Horizontal Temperature Distribution.

Furnace,	А.	Temp., ° O., at *	C.	Temp. Difference from A. ° C.
X	1546	1542	•••	4
	1506	***	1505	ĩ
\boldsymbol{z}	1531	1542	***	7
	1517	***	1509	8

* A = near centre of furnace. B = near door, with steel only 3 in. deep, as near sill as practicable. C = near launder, i.e., at right angles to line AB.

Comparison of Thermocouple and Optical Pyrometer on Acid Open-Hearth Furnace.

Messrs. Thos. Firth and John Brown, Ltd., have recorded the results of three comparisons in Fig. 9. The quick-immersion thermocouple was always immersed to a depth of 8 in., while the optical pyrometer, of the disappearing-filament type, was sighted on the slag with the gas off during reversal. The following points are noteworthy:

(1) During the melting period, the optical-pyrometer readings do not give a true indication of the bath temperature. At the beginning they may register as much as 80° °C. higher than the immersion pyrometer, the difference gradually diminishing up to the boiling period.

(2) During the boil, agreement is generally within 10–15° C., although differences as great as 25° C. have been noted. The thermocouple more often reads the higher, but this is not the

invariable rule.

(3) When boiling has ceased and finishings have been added, the optical pyrometer generally reads the lower.

From the above observations it appears likely that only during the boiling period does the optical pyrometer give even approximately the temperature of the bath. Trough Temperatures.

Messrs. Wm. Jessop & Sons, Ltd., record the results of two

experiments.

The first was carried out on three 8-ton ingots, two of which were cast from a double-nozzled trough and the third from a single-nozzled trough.

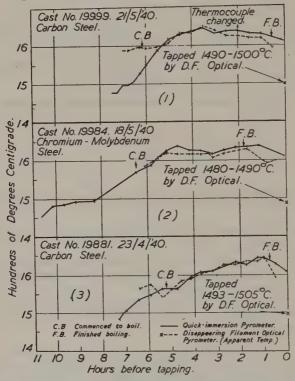


Fig. 9.—Comparison between Quick-Immersion and Disappearing-Filament Optical Pyrometer Indications. Acid open-hearth furnace.

Temperatures were measured near the centre and at each end of the large trough:

Double trough: Centre . . . 1545° C.
Right end . . . 1541° C.
Left end . . . 1542° C.
Single trough: Centre . . . 1547° C.

The time between the two sets of readings was about 10 min.; 25 tons of steel were cast in all from a ladle full to capacity.

The second experiment was conducted on a series of eight

3-ton ingots. Temperatures were measured in each trough, except the sixth, which was rather inaccessibly placed. Two pyrometers were used, and to check their relative calibration they were dipped successively in the last trough. The difference in temperature recorded was only 2° C. The results of the experiment are shown in Fig. 10. It will be seen that all eight readings fall within a range of 3° C., and it is not possible to detect any definitely assignable fall in temperature during the half-hour taken to complete the ecasting.

Emissivity and Optical Pyrometry of Liquid Steel Streams.

In a paper entitled "High Temperature Measurement in a Steel Works," the result of an investigation, carried out by Messrs.

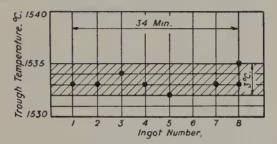


Fig. 10.—Trough Temperature Readings during the casting of eight 3-ton ingots.

Hadfields, Ltd., in which the quick-immersion thermocouple was employed, has been given. This work, so far as it concerns the

thermocouple, is briefly summarised below.

A number of steels were melted in a high-frequency furnace and poured at various temperatures, ranging from 1470° to 1690° C. as determined by a quick-immersion thermocouple, simultaneous observations being taken with an ordinary disappearing-filament pyrometer or by a "colour" pyrometer of the type recently developed in Germany. The last-mentioned instrument is designed to give slightly biassed readings of colour temperature (which, it is claimed, represent the true temperature of the steel), and in addition a measurement of brightness temperature based on a combination of two wave-bands, in the red and green—an arrangement considered superior to the use of a single wave-band in the red, as employed in the ordinary disappearing-filament pyrometer. Some twenty steels were observed, the majority being carbon steels and the remainder alloy steels containing chromium, nickel or copper.

With the disappearing-filament pyrometer the differences between the true and observed temperatures for all the steels,

¹ W. J. Todd, Metal Treatment, 1939-40, vol. 5, p. 171.

except a single specimen containing 1.8% of carbon, showed a spread at any temperature of $\pm 25^{\circ}$ or $\pm 30^{\circ}$ C. from the mean difference. This mean difference in the region of $1600-1640^{\circ}$ C. was of the order of 130° C., corresponding with an emissivity of 0.4, the figure commonly used in works practice for correcting optical-pyrometer observations. A further point, not previously established, was that the emissivity is not constant but decreases somewhat with rise in temperature over the range investigated.

With the other pyrometer, the brightness measurements, excepts for those on two steels, showed a spread of about \pm 40° C., with differences from the true temperature of the same order as with the disappearing-filament pyrometer. The two abnormal steels gave brightness temperatures some 130° C. higher than the others, so that these particular readings approximated to the true temperatures

without the application of the usual correction.

On the colour scale, the average readings for the steels, excluding the three alloy varieties, agreed with the true temperature at about 1600° C., the departures above and below this temperature corresponding closely with the departures from the values at 1600° C. shown by the two sets of brightness measurements referred to above. The spread of the observations for the individual steels was as much as \pm 35° or \pm 40° C., while the three alloy steels differed by some 100° C. from the mean of the other steels.

It will be seen from the observations that the claims made for the German instrument are conclusively disproved, the accuracy of its readings of both kinds being inferior to those of the disappearing-filament pyrometer. Even with the latter instrument, however, the spread of the observations for individual steels shows that an uncertainty in assessing the true temperature of at least \pm 25° C., and possibly much more, must be reckoned with.

This is not to say that the disappearing-filament pyrometer will not continue to perform a useful function. In fact, now that the temperature can be accurately measured by the quick-immersion thermocouple, the information which the optical instrument affords as to emissivity may enable the complex phenomena which occur

in steelmaking to be more clearly understood.

C.—The Possibility of Control.

In the preceding Part examples have been given of the application of the quick-immersion thermocouple to a number of special problems. In addition, numerous observations have been made with a view to an accumulation of data culminating in a routine of temperature control at different works. Some examples follow.

Messrs. Hadfields, Ltd.

Considerable use of the immersion thermocouple in the measurement of the temperature of molten steel has been made in the

works of Messrs. Hadfields, Ltd., during a period now amounting to four years. The method has been applied in open-hearth, electric arc and high-frequency furnaces for both routine control

and investigation purposes.

In open-hearth furnaces the couple has now been in use as a routine control instrument for some nine months. It is particularly valuable in indicating bath temperatures at the commencement of "oreing" in the acid process, and in giving indications of bath temperature during the refining stages. Previous to this, recourse has been had to the use of the disappearing-filament pyrometer, the means of application being the observation of the temperature of the slag during reversal. This method had been in use since 1923.

In the foundry its use for the determination of casting temperatures from ladles and shanks has been valuable, particularly in determining the limitations of the use of the optical pyrometer, which has for this class of work a more ready adaptability. The time taken up by the use of the immersion couple in dealing with steel during the casting operation imposes some limitation on its use, but it has been of service in investigating questions of the fluidity of molten steel, the determination of emissivity and its correlation with such factors as steel composition, and the influence of deoxidant additions and secondary reactions between the molten steel and the refractories used in furnaces and ladles. The limitations of the use of the optical pyrometer due to variations of emissivity, under foundry conditions as distinct from those prevailing in open-hearth and electric-furnace ingot practice, had long been realised.

Messrs. Thos. Firth and John Brown, Ltd.

The following report has been made as to the position at these works:

Temperature control of the open-hearth furnaces before installation of the immersion thermocouple had been by means of the disappearing-filament optical pyrometer, the practice being to measure the slag temperatures during the gas reversals—gas off—through the partially raised door during the boiling period. The practice at the date of writing is to make routine temperature measurements with both the disappearing-filament and the immersion pyrometers, on as many heats as can possibly be covered by one set of apparatus, this amounting to approximately 30% of the total heats. Readings are taken every half-hour during the boil and prior to tapping with the immersion pyrometer. A standard immersion depth of approximately 8 in. is maintained for immersions which are taken through the centre door, and readings obtained are used as a guide for furnace control. It has not yet been established how closely these measurements represent a true average temperature of the whole of the bath. It is hoped, however, to be

able to carry out some exploratory experiments on bath temperatures in the near future.

Tapping-temperature control of high-frequency-furnace melts, chiefly on experimental heats, is carried out with the immersion thermocouple, again maintaining the standard immersion depth. The practice here is to make three or four immersions during the last ten minutes of the melt, adjustments being made to the current supply according to the readings obtained.

Immersions prior to casting have been made in crucibles of steel poured from the high-frequency furnaces. These have enabled us to make castings at a more definite range of temperature than

hitherto.

English Steel Corporation, Ltd.

The question of temperature control has received attention at the Vickers Works, where the output from the extensive arcfurnace plant is closely controlled. This works reports as follows:

Before the advent of the quick-immersion thermocouple, when the optical pyrometer was the only method of taking temperature measurements on liquid steel, the results obtained were not sufficiently reliable to enable the steelmaker to use them for controlling the metal in conjunction with the other recognised features of steel practice. It is true that temperatures taken by optical means when tapping the metal into the ladle under the best conditions might give some idea as to whether the steel was too hot for casting purposes, and the ladle could, therefore, be held for a calculated period of time, but in the furnace it was impossible to gauge with any degree of accuracy the actual temperature of the steel, and consequently any real temperature control was out of the question.

Now that the temperature of the metal can be accurately determined by direct contact, the question of the effect of the temperature upon the condition of the steel in the bath can be investigated with more reliability than hitherto. This is an important step, since the temperature of certain stages can have a decided influence upon the subsequent "cleanliness" of the steel, and proof of this has been forthcoming since the quick-

immersion method has been employed.

For electric arc furnace steel, therefore, a definite procedure has now been laid down, a minimum temperature being specified during the period when the steel is clear-melted to slagging, to ensure really satisfactory boiling down of the metal. The furnace is further controlled from the white-slag period to the tapping operation, so that a sufficiently high, but not excessive, temperature is attained, which must materially assist in ensuring that the proper chemical reactions take place.

The following are results taken from the records obtained on aircraft steel, working on the normal routine basis in the electric

arc furnace; the temperatures were taken in each case in the centre of the bath (depth of immersion, 9-10 in.) after rabbling with the power off and the electrodes raised:

Temperature Measurements in Electric Arc Furnace.

				Temper	atures. °C.		D
Condition of Bath.		1.	2.	8.	4.	5.	6.
Prior to boiling .		1612	***	1614	• • •	1598	1606
During boiling .		1633	1624	1627	1614	1612	1628
Prior to slagging		•••	1612	1608	1623	1610	
White slag .		1602	1603	1605	1607	1600	1605
Prior to tapping		1617	1604	1616	1608	1603	1618
Ladle	•	1593	1591	1602	1596	1587	1604

Messrs. Wm. Jessop & Sons, Ltd.

The greater part of the output of this firm is subject to temperature measurement and control by the quick-immersion method. Three pyrometers are kept for the high-frequency furnace, on which readings are made every half-hour, while two other pyrometers are in regular use on arc furnaces and eight on open-hearth furnaces.

This firm have expressed the following views on the question

of temperature control:

The manufacture of quality alloy steels has in the past been left too much to human judgment, with all its unsuspected variations. The estimation of temperature is one important factor which cannot satisfactorily be left to unaided observation.

We have a right to enquire into the practical usefulness of the quick-immersion technique, and the following discussion is directed

to that end.

Effect of Temperature on the Rate of Chemical Reaction.— Most steelmaking processes involve a refining period in which the chemical processes of oxidation and reduction take place. The rate, k, of a bi-molecular chemical reaction involving an activation energy E normally follows a law of the form:

$$k = Z\sqrt{T} \times e^{-\frac{E}{RT}}$$

at high temperatures, so that if k_1 is the rate at temperature T_1 and k_2 is the rate at temperature T_2 :

$$\frac{k_{1}}{k_{2}} = \sqrt{\frac{\overline{T}_{1}}{T_{2}}} \cdot e^{\frac{E}{R} \left(\frac{1}{T_{2}} - \frac{1}{T_{1}}\right)}.$$

The following are the calculated ratios by which reaction rates will be increased for an increase of 50° C. at various temperatures and for three typical values of the activation energy:

Ratios of Increase of Reaction Rates.

	•		
Temp. Increase.	E = 10,000.	E = 45,000.	E = 80,000.
1400° to 1450° C.	1.1	1.5	2.0
1500° to 1550° C.	1.1	1.4	1.9
1600° to 1650° C.	1.1	1.4	1.8
1650° to 1700° C.	1.1	1.4	1.7

In steelmaking the chemical reactions are, of course, of much greater complexity than the simple case considered above. The system consists of three phases, each comprising several components. Nevertheless, similar considerations will obtain and the effect of temperature will be of the order given. The effect will, indeed, be considerably increased by the variation with temperature of such factors as the viscosity of the slag and the surface tension of the slag-metal interface.

It is therefore not unlikely that chemical reaction rates may vary by as much as two to one as a result of changes of temperature which lie within the range of uncertainty when only optical pyrometers are available for measurements. The advantages of an accurate immersion temperature under these circumstances are

obvious.

Acid Open-Hearth Practice.—In our opinion two immersion temperatures should be observed as a minimum:

(a) The temperature of the metal immediately prior to

(b) The temperature of the metal at the "going-on"

stage

The temperature of the liquid metal at the time when oreing commences has a considerable effect on the ultimate cleanness of the steel. Under these circumstances it is clear that an exact determination of temperature at this stage is a real practical advance on previous methods depending on spoon samples and back-wall optical readings. We have found it advisable to fix a minimum immersion temperature at stage (a) to ensure completely satisfactory

refining conditions.

The temperature at stage (b) is scientifically significant, because then the slag and metal are approaching equilibrium. The temperature at this stage also affects the cleanness. It is important to attain a sufficiently high temperature to encourage the formation and fluxing-out of aggregates of the non-metallic deoxidation products. On the other hand, too high a temperature will increase the absorption of gases, and so result in casting difficulties. Although the temperature will be modified a little by the later additions, an accurate temperature measurement at the going-on stage forms a base-line value on which to judge whether a heat is "hot," "normal" or "cold," and it is not too late to take steps to modify conditions before risking tapping the furnace.

We deduce, therefore, that there is a strong case for improving the control of the furnace so as to avoid undesirable extremes of

temperature at this stage.

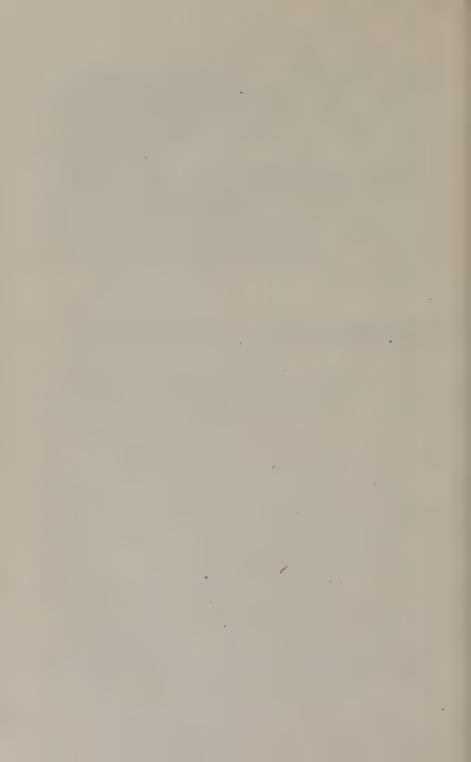
Temperature Control in the Foundry.—The high-frequency furnace is used for melting special steel, such as for cast permanent magnets and quality carbon steels required for aircraft. The small-casting production totals many thousands each week and the

value of accurate temperature control has been proved in practice. When each individual heat of metal is tested for temperature by the specially designed quick-immersion pyrometers, the foundry scrap castings which result are reduced between two- and fourfold as compared with what obtains under similar conditions when an optical pyrometer only is used as a guide or when merely an "experienced eye" is used to judge the tapping temperature. With comparatively small melts of steel or alloy it is specially difficult to obtain optical-pyrometer readings which are significant, owing to slag and surface contamination of the bare metal.

In the main foundry successful efforts have been made to measure the temperature of the metal in the ladle immediately prior to casting, and the indications are that benefit would result from a more extended survey of foundry temperatures. The principal use of the new technique, however, is to ascertain the liquid steel temperature in the furnace and so avoid sluggish metal being

tapped into the ladle.

[This Report was discussed jointly with the following paper by D. A. Oliver and T. Land on "The Temperature Distribution in the Liquid Steel in Various Steelmaking Furnaces."]



THE TEMPERATURE DISTRIBUTION IN THE LIQUID STEEL IN VARIOUS STEELMAKING FURNACES.*

By D. A. OLIVER, M.Sc., F.Inst.P., and T. LAND, M.A. (RESEARCH DEPARTMENT, MESSRS. Wm. JESSOP & SONS, LTD., SHEFFIELD).

(Figs. 1 to 3 =Plate XXV.)

Paper No. 10/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee).

SUMMARY.

Temperature distributions in three dimensions in the liquid steel in different types and sizes of steelmaking furnaces are recorded in this paper. Measurements of temperature were made by the Schofield-Grace procedure, which proved to be well suited to the making of temperature surveys. The detailed observations are given in pictorial form and embrace 40- and 25-ton acid open-hearth furnaces, 12-ton, 3-ton and 30-cwt. basic electric arc furnaces, together with a small 100-lb. high-frequency furnace with a basic lining. The results are also summarised in a Table which shows the maximum observed variations in both the vertical and the horizontal directions corresponding to different stages in the melting processes. These variations lie between zero and 45° C. Very small differences from point to point were found in all types of furnace when the metal bath was on the boil, but larger temperature variations were built up during the finishing stages when the stirring action of escaping gases was negligibly small. Mechanical stirring by rabbling resulted in greater equalisation, and is recommended prior to an immersion reading when precise control is being exercised. Finally, reasons are given for concluding that, subject to a suitable position being chosen for measuring the temperature, the observed single value is likely to be representative of the mean temperature under normal conditions to within $\pm 10^\circ$ C., or to within $\pm 20^\circ$ C. under extreme conditions.

1.—Introduction.

A SURVEY of the published literature on the physical chemistry of steelmaking processes reveals in otherwise excellent work serious vagueness regarding the actual temperatures attained, thereby handicapping the correlation of large-scale work with more precisely conducted laboratory experiments. This state of affairs was practically universal until the advent of the Fitterer ⁽¹⁾ and the Schofield-Grace ⁽²⁾ types of thermo-electric immersion pyrometers, of which, so far as Great Britain is concerned, the Schofield-Grace type can be regarded as the unchallenged survivor. Five years ago measurements at isolated points in a bath of liquid steel were somewhat precarious achievements of a research character, and it took many months before the real potentialities of the Schofield-Grace

^{*} Received March 4, 1942.

technique were realised for routine measurements of liquid steel temperature. An account of recent progress in pyrometer design and instrumental technique has recently been published. The object of the present paper is to extend the study of the subject to include data on the temperature distribution in various types and sizes of steelmaking furnaces. These data enable one to examine the validity of taking a quick-immersion reading of temperature at a single point to be representative of the whole mass of molten steel.

Such an examination of temperature distribution under typical steelmaking conditions appears essential before complicated studies of the physical chemistry of steelmaking itself are separately undertaken. If any justification is needed for this view, it is only necessary to recall the high dependence of chemical reaction velocity upon temperature for most of the reactions which take place in the steelmaking process, which implies that a lack of knowledge of local temperature conditions is equivalent to ignorance of precise local reaction rates. Chemical considerations will not be discussed in this paper, attention rather being focused on the governing physical factors which determine the temperature distribution.

2.—Review of Previous Work.

When the Liquid Steel Temperature Sub-Committee was set up it rightly first concentrated its attention on perfecting a suitable pyrometer. It was clearly recognised at an early date that, before temperature control could be instituted with confidence, it would be necessary to explore the temperature variations in the bath. Some preliminary evidence was published in the Second Report of the Sub-Committee (2) and showed that differences of 18° C. occurred under certain circumstances in open-hearth furnaces. In the Third Report (4) of the Sub-Committee further details of temperature variations were given. A study of the difference between temperatures measured at depths of 1-2 in. and 6-7 in. in a 10-ton electric arc furnace was presented by The United Steel Companies, Ltd. The results of these temperature measurements showed that, except when the bath was on the boil, the metal near the surface was approximately 20° C. hotter than that at a depth of 6 in. During the boiling period no difference in temperature could be detected. The English Steel Corporation, Ltd., reported similar measurements on the same type of furnace and found that, after rabbling, the steel at a depth of 4-6 in. was 0-8° C. hotter than that at 9-10 in. In the same Report the authors' firm contributed some data on small are furnaces which are embraced in the present paper. Although these preliminary surveys gave an indication of the order of temperature variations likely to be encountered, there was still need for a more comprehensive investigation. The surveys reported in the present paper confirm and extend the results of the earlier work.

3.—Scope of the Investigation.

The choice of the mode of approach was limited as in most full-scale experiments. Only certain types and sizes of furnace were available and observations had to be taken with a minimum dislocation of production. The initial object was, therefore, to obtain observations on a wide range of furnaces under as many different conditions as possible.

Surveys have been made of the following:

(1) 40-ton Siemens acid open-hearth furnace.
(2) 25-ton Siemens acid open-hearth furnace.

(3) 12-ton electric arc furnace (3-electrode Héroult type).
(4) 3-ton electric arc furnace (2-electrode, bottom-return

(5) 30-cwt. electric arc furnace (2-electrode, bottom-return

(6) 100-lb. high-frequency furnace.

It was not possible to explore all the furnaces with equal thoroughness, but sufficient information has been obtained to draw useful conclusions and guide future work. No surveys have been made of basic open-hearth furnaces.

4.—Method of Measurement.

In Great Britain the Schofield-Grace quick-immersion technique is rapidly superseding all other methods of liquid steel temperature measurement. This method was used throughout the present investigation and is in operation as a routine control on all the furnaces surveyed. It is particularly suited to determinations of temperature variation in the melting furnace. Since the platinum/platinum-13%-rhodium thermocouple is enclosed in a very thin silica sheath it very rapidly takes up the temperature of the surrounding metal when moved from point to point in the bath.

The pyrometers and measuring instruments used in routine control have already been described (3) and were used with small modifications in the present surveys. The pyrometers were all sufficiently light to be put into the furnaces by hand, and enabled temperatures to be taken at points up to 9 ft. through the furnace door and at up to 19 in. below the slag surface. The investigations in the larger furnaces were made with pyrometers of

a type the end of which is illustrated in Fig. 1.

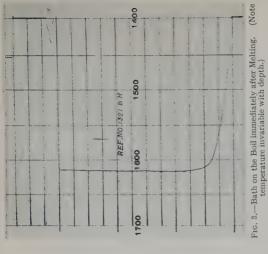
Electromotive forces were measured by skilled observers using calibrated self-contained potentiometers of high accuracy with very open scales, unless the recorder mentioned below was employed. The temperatures were deduced from a table of e.m.f.s based on values of 18·18 mV. at the melting point of palladium (1555° C.) and 21·11 mV. at the melting point of platinum (1773° C.) for cold

junctions at 0° C. Due precautions were taken to avoid spurious results arising from contamination, new thermojunctions being used whenever possible. Most of the observations were taken with a single pyrometer, which was moved from point to point in the bath. When observations were taken through different doors of a furnace, one pyrometer was used through each door. Check measurements on different pyrometers in the same region of liquid steel showed agreement within 2° C. The maximum difference between different pyrometers is assessed at less than 4° C. The observations at different depths were taken successively from the top downward to avoid any cooling effect which the pyrometer head might have on

the surrounding steel. Certain observations were made with a recorder and amplifier of novel design which have been specially developed (5) for determining the temperature of liquid steel and are used for routine temperature measurements. Fig. 2 shows a record made during an experiment on a 12-ton electric arc furnace. The horizontal lines on the chart indicate five-second intervals. The chart record shows quite clearly the method adopted in the temperature surveys, and gives an idea of the precision and sensitivity of the observations. At A the thermocouple had attained the temperature of the metal at a depth of $2\frac{1}{2}$ in. It was then immersed to a depth of 10 in. and reached a steady temperature at B. The pyrometer was further immersed to 19 in., C, and finally raised again to 6 in., D. The small hump in the curve between B and C records the fact that the buoyancy of the pyrometer in the steel twisted the pyrometer in the hands of the operator and the thermojunction rose momentarily to a smaller depth. At E is the record of the amplifier and recorder being calibrated at 1650° and at 1450° C. against a Weston standard cell incorporated in the amplifier equipment. This operation is performed merely by depressing a switch. After the experiment extra power was put on the furnace for 10 min., the bath was again rabbled and a routine measurement was made at a depth of 6 in. with a different pyrometer. The record is shown at F. The temperature at F compared with that at D at the same depth has risen by about 5° C. and a further effect of the extra heating is seen in the hump at the end of the curve. This was made as the pyrometer was withdrawn through the slag, which had been heated to more than 20° C. above the metal temperature. The silica tube used in this particular survey was nearly twice as thick as those normally used. It allowed only four measurements to be made in the 60 sec. during which the pyrometer was in the furnace. Normally it was possible to obtain six or seven readings in that time.

5.—Results of Temperature Surveys.

The details of the temperature surveys are set out in Figs. 2 to 9. The values on the diagrams give the difference ΔT between each temperature and the temperature measured at a possible position



temperature invariance with depuir,
Fros. 2 and 3.—Records of Temperature Surveys at Different
Depths in a 13-ton electric arc furnace.

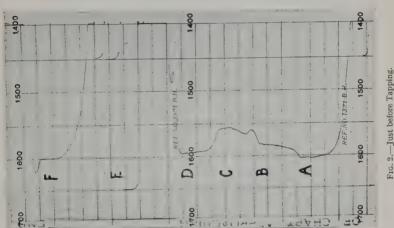




Fig. 1.—Head of Special Pyrometer for temperature measurements at different depths.

[Oliver & Land. [To face p. 248 p.



for routine control. The test position relative to the furnace bottom and the slag surface is indicated by a full circle. The broad features of the furnaces are shown in Figs. 10 to 14. Whenever possible, observations were taken at a uniform depth at points distributed over one-half of the bath, and at different depths at one or more points in the bath. The temperatures were measured at stages in the steelmaking process likely to yield extreme results or at times considered significant for the purposes of control.

For easy reference the results of the surveys in the open-hearth

and arc furnaces are summarised in Table I.

Table I.—Temperature Variations in Steelmaking Furnaces.

		Variation. ° C.					
Bath Conditions.	Horiz	zontal.	Vertical.				
	Max.	Min.	Max.	Min.			
(a) Acid Open-Hearth I	urnaces, 40)-ton and	25-ton.				
Just before oreing Just before going-on Just before tapping	9 20	5 6	$\begin{matrix} 0\\4\\16\end{matrix}$	0 0 5			
(b) Basic Electric Arc Fu	rnaces, 12-t	on (Hérou	lt Type).				
After slagging off, before adding finishing slag				0 5			
(c) Basic Electric Arc Furnace Bottom-Return			$Two extit{-}Elect$	rode,			
Just before tapping	11	4	18	7			

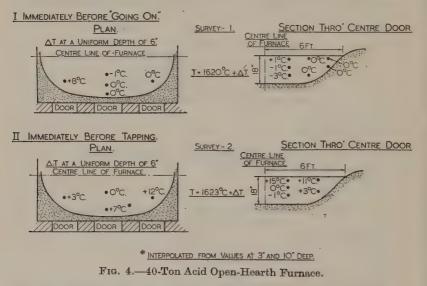
(a) Open-Hearth Furnaces.

In the open-hearth furnaces the surveys did not extend quite to the centre-line of the furnaces. In order to check the assumption that there is no further large temperature variation beyond the centre-line a specially long pyrometer was used, which enabled a temperature test to be taken only 3 ft. 6 in. from the far bank of a 25-ton furnace. The results for two typical bath conditions are shown below; they confirm the assumption that no very large variations occur across the bath:

		Temp	erature. Dista	nce from Near	Bank-
Bath Condition.	ř	9 in.	2 ft.	4 ft.	7 ft.
During addition of lime		1650° C.	1650° C.	1648° C.	1648° C.
Just before tapping / .		1617° C.	1617° C.	1612° C.	1612° C.

It will be seen from Table I. (a) that while the bath was on the boil the stirring action of the evolved gases maintained a remarkable

degree of uniformity of temperature. This uniformity persisted even when the rate of oxidation of the carbon had been reduced to a low value at the going-on stage. After the addition of deoxidising agents the temperature of the bath became considerably less uniform, and variations of up to 20° C. were observed. However, the value of the temperature measured at the standard position used for routine control never differed by more than 6° C. from the unweighted mean of all the temperature measurements in that survey. The general tendency of the results is to show rather higher temperatures towards the edges of the bath than at the centre. Survey 6, Fig. 5, however, is an example of the reverse effect. The shape and direction



of the flame will no doubt have a large influence on this variation. In all cases of vertical temperature variations a gradient was found from the hot surface to cooler metal near the furnace bottom.

In the initial experiments the direction of the flame was not noted, as it was thought that the slag layer would even out temperature fluctuations due to the flame. In a special experiment, half an hour before tapping a 25-ton acid furnace, temperatures were measured at the same depth, through each of the three doors. The gas was passing from right to left, and the temperatures were as follows:

Left Door. Centre Door. Right Door. 1634° C. 1625° C. 1635° C.

It seems that the direction of the gas flame has the cumulative effect of keeping the ends about 10° C. hotter than the middle of the

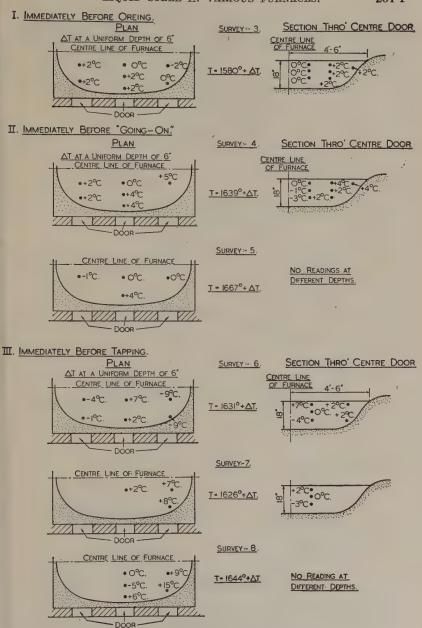
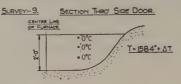


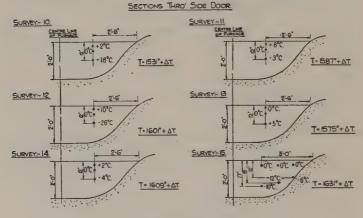
Fig. 5.—25-Ton Acid Open-Hearth Furnace.

bath at this stage in the melt. There is, however, little evidence of the temperature of the metal under the slag at one end rising much during the time that the gas flame is directed from that end.

I IMMEDIATELY AFTER SLAGGING OFF, METAL BARE, BATH STILL ALIVE, NO RABBLING.



II 15-MINUTES BEFORE TAPPING; 1 TO 4 MINUTES AFTER "RABBLING"



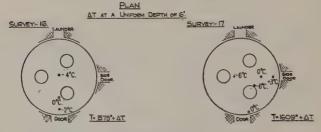


Fig. 6.—12-Ton Héroult-Type Arc Furnace.

(b) Electric Arc Furnaces.

Furnaces of this type have been surveyed in particular detail and the results are of considerable interest. As in the case of the acid

PLAN

AT AT A UNIFORM DEPTH OF 6".

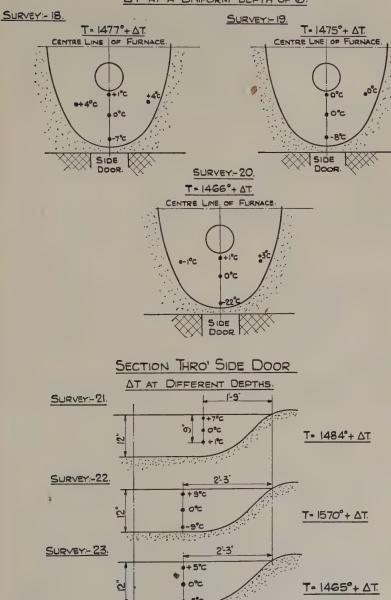
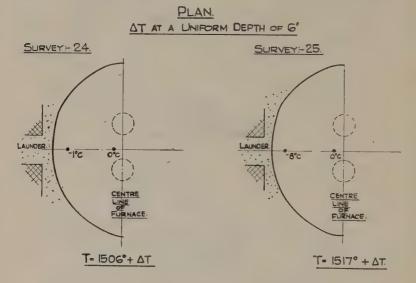


Fig. 7.—3-Ton Electric Arc Furnace (bottom return).

open-hearth furnace, the temperature while the bath is on the boil is remarkably uniform. Fig. 3 is a record of a survey made shortly after melting, and shows the temperature at points $2\frac{1}{2}$ in., 7 in., 13 in., and 19 in. deep, again at 7 in. and finally at 6 in. close to the bank. The only variation that can be detected is a drop of about



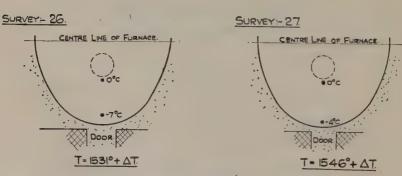


Fig. 8.—30-Cwt. Basic Electric Arc Furnace (bottom return).

2° C. during the course of the experiment, which was carried out with the electrodes raised, without previous rabbling.

When the finishing slag had been added the bath began to build up temperature differences. The variation from point to point at a constant depth seemed to be very small. Large differences were, however, found in the vertical direction. The observations in each survey were taken after rabbling the bath, and the rather different results reflect a variation in the effectiveness of mixing. It seems clear that, under the conditions of operation encountered, the top 12 in. of the metal normally vary in temperature by about 15° C. Below this depth there is frequently a cool layer which is not always greatly disturbed by the process of rabbling. The metal within 2 or 3 in. of the bottom of the bath has occasionally been found to be 50° or even 70° C. below the temperature of the hot metal above it.

A rough calculation shows that, for the size of furnace at present under consideration, the uniform temperature layer comprises about three-quarters of the metal in the furnace. The average temperature of the remaining cooler metal may be 20° or even 30° C. below that of the upper portion. A temperature test taken at a depth of 6 in. below the surface should, however, give the average temperature of

the whole bath with an error of not more than 10° C.

The small size of the other arc furnaces investigated enabled a much more thorough mixing to be achieved, and variations in temperature rarely exceeded 10° C. The same general trends are observed as in the larger furnaces.

(c) High-Frequency Furnace.

The metal in a high-frequency electric furnace undergoes very violent agitation when the heating current is passing through the However, temperature measurements are frequently made with the heating current switched off, and it was thought advisable to investigate the uniformity of temperature under these conditions. The temperature was investigated in a small 100-lb. high-frequency furnace having an internal diameter of 7 in. The radial thickness of the lining of rammed magnesite was 1 in. The steel filled the furnace to a depth of 10 in. and the thermocouple was protected by a thin silica tube 12 in. long. This slender tube was prevented from bending by enclosing all but the bottom 2 in. in a thicker silica tube. The temperature was measured successively at the top, middle and bottom of the furnace, and then at each position again, over a period of a minute. The cooling curve for each position is plotted in Fig. 9. The temperature at the bottom of the furnace initially falls much more quickly than at other positions, but later there is a slower cooling rate at the bottom and the temperature then falls more rapidly at the centre and near the top. The explanation is, of course, that the metal near the sides cools rapidly by conduction through the furnace walls, and falls to the bottom of the furnace to build up a cool layer, which remains at a relatively steady temperature. The observation showing a fall of 20° C. after 10 sec. was taken next to the wall of the furnace at a depth of 2 in.; it falls on the same curve as temperatures measured at the bottom of the furnace.

It would appear that a temperature determination made at a

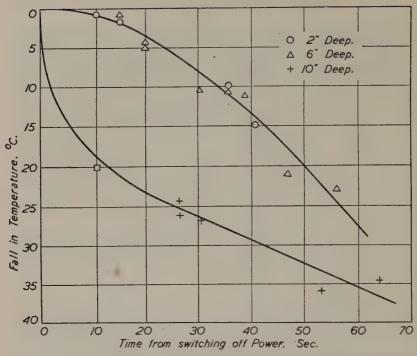
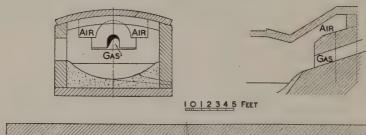


Fig. 9.—Cooling of Metal at Different Depths in a 100-lb. High-Frequency Electric Furnace with the Heating Current Switched Off.



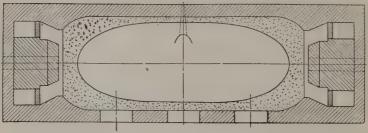


Fig. 10.—40-Ton Acid Open-Hearth Furnace.

depth of 4 in. is likely to differ from the true mean temperature by less than 10° C.

6.—Conclusions.

The observations show that during the period when the bath is on the boil the temperature is very uniform. This uniformity persists in the acid open-hearth furnace even when the activity of the

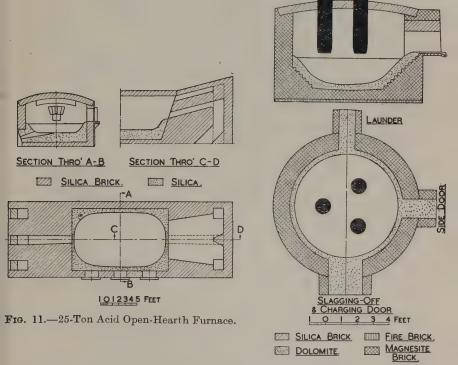


Fig. 12.—12-Ton Basic Electric Arc Furnace (Héroult type).

bath is quite low and the bath is approaching equilibrium at the going-on stage. The degree of uniformity will depend on the activity of the bath and during the boiling period will vary between \pm 2° and \pm 5° C. When the bath is killed and quiescent, greater temperature gradients begin to build up. The vertical gradient appears to be about 10° C. per ft. in the acid open-hearth furnaces and the maximum horizontal variation at a constant depth is about 15° C.

The horizontal variation seems to be less regular and may in part be due to the distribution of cold additions and to the form of the gas flame. In the basic electric arc furnaces the vertical gradient tends to become considerably greater than in acid open-hearth furnaces and is only kept within reasonable limits by frequent

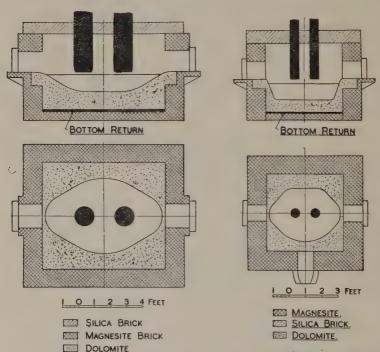


Fig. 13.—3-Ton Basic Electric Arc Furnace (3-phase, bottom-return type).

Fig. 14.—30-Cwt. Basic Electric Arc Furnace (3 - phase, bottom-return type).

rabbling. The usual degree of rabbling keeps the gradient down to about 10° C. per ft. in the upper layers, although temperature differences of more than 50° C. may be encountered near the furnace bottom. If, therefore, a suitable place is chosen for taking a single observation of the temperature of the liquid steel, it can be deduced that the result obtained will not usually differ by more than $10-15^{\circ}$ C. from the true average temperature of the bath. On the instrumental side, owing to thermocouple effects and the unavoidable errors of observation, there is a further possible error of \pm 5° C. The final absolute uncertainty may thus approach \pm 20° C., but in most normal cases the error is likely to be of the order of \pm 10° C. This degree

of accuracy is considered quite satisfactory for the large majority of cases, although there may be occasions when it would be advisable to make several measurements at two or more locations in the bath.

Acknowledgment.

The authors wish to express their thanks to the Members of the Liquid Steel Temperature Sub-Committee, under the Chairmanship of Mr. E. W. Elcock, for helpful comments when the subject matter of this paper was first presented to the Sub-Committee.

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This paper was discussed jointly with the preceding "Third Report of the Liquid Steel Temperature

JOINT DISCUSSION.

The Third Report of the Liquid Steel Temperature Sub-Committee and the paper by D. A. Oliver and T. Land on "The Temperature Distribution in the Liquid Steel in various Steelmaking Furnaces" were discussed jointly.

Dr. C. H. Desch, F.R.S. (Vice-President; Iron and Steel Industrial Research Council, London): The work of the Liquid Steel Temperature Sub-Committee represents one of the most useful results of the research organisation which has been set up in connection with the steel industry. To anyone not familiar with steel-works practice it might seem a fairly simple matter to determine the temperature of liquid steel. One ordinarily determines the temperature of a liquid metal by immersing a thermocouple in it. The temperature of liquid steel is below the melting point of platinum, and so it might seem that that would be an easy thing to do. As a matter of fact, for very many years past people have sought to determine the temperature by the use of immersion thermocouples without success; there have always been difficulties due to the breakdown of the couples themselves and particularly to the failure to find refractories of sufficient resistance to attack. It has been necessary, therefore, to fall back on the optical pyrometer, which can really be used only when the metal is being tapped; it is extremely difficult to use it inside the furnace, which is where one wants to know the temperature, and it is subject to the large correction for emissivity, whilst the emissivity of these materials, as we know, is not a constant, so that there are all kinds of sources of error.

The difficulty was so great that, when the Sub-Committee was first set up, the suggestion was made that it might be necessary to abandon both the thermocouple and the optical methods, and try to find some other physical property which could be used for measuring temperature. However, the Schofield-Grace design of pyrometer proved to be extremely useful. Anyone not familiar with the subject, and taking up this Report, might say "Yes, this seems fairly obvious; this is the kind of thing one would naturally do." Actually, however, it took a great deal of work before it was possible to find the particular arrangement of the couple and suitable refractories for giving a satisfactory result; but now, I think, it is admitted that the immersion pyrometer in the form used and recommended by the Sub-Committee can be used in steelworks practice generally, not only for taking the average temperature of steel but also for exploring the distribution of temperature, as in the paper by Mr. Oliver and Mr. Land. That is going to be an extremely important matter.

The authors have perhaps been a little conservative in stating the degree of accuracy of the couple. Before very long, I think that they will be able to fix closer limits than they have done now. The introduction of the carbon sleeve in place of an ordinary refractory sleeve makes it possible to use the couple under basic conditions as well as under acid, and it thus becomes obvious that in future those steelworks which are sufficiently interested to take up the problem of the exact physico-chemical control of the bath before tapping will have in their hands a very powerful implement for measuring temperatures. It has been mentioned also that the instrument has been made in a recording form, so that a permanent record can be taken of the conditions in successive casts, which should be extremely useful in arranging for the control of melting and refining.

When we remember the attempts which have been made to devise new couples with out-of-the-way materials for measuring the temperature of liquid steel, and compare those with the extremely simple solution which has been found, we must congratulate the members of the Sub-Committee and those gentlemen at the National Physical Laboratory who carried out the scientific work on the

very successful results of their labours.

Dr. F. H. Schofield (Freshwater, Isle of Wight): There is one rather striking fact about these two papers. The first, the Report of the Sub-Committee, sets out a number of problems for which a solution is wanted, and the Sub-Committee have drawn up a programme of investigation; and then we have this second paper, by Mr. Oliver and Mr. Land, which gives almost complete answers to some of these questions. I do not think that I have ever met a case of the same kind before, where we have had at one and the same Meeting the discussion of a programme of projected work and at the same time some completed work presented for consideration. It is clear that Mr. Oliver and Mr. Land have set a very hot pace in this field, and I hope that they will continue to do so.

The paper by Mr. Oliver and Mr. Land is, of course, the first really systematic study of the problem of distribution, and they answer two questions which were put by the Sub-Committee. The first is, is the furnace ever uniform at any stage, and particularly at the boiling stage? The answer is a decided Yes; moreover, it is stated that the uniformity persists for a considerable time. The second question is, when you come to the time of tapping, will a single reading suffice to give you the mean temperature of the bath, or what may be called a "representative temperature"?—for it need not be the mean temperature, provided that it differs from the mean temperature by a certain quantity, which will be the case if there exists a certain pattern of temperature distribution in the bath. Here, again, Mr. Oliver and Mr. Land-are able to give the answer Yes, within certain limits which are not impossibly wide; + 10° and + 20° C. have been referred to.

Both of these are important results, and they hold out, I think,

high promise for the ultimate attainment of temperature control. The subject is, of course, a large one, and much remains to be done; but here I should like to say how simple the path is made for anyone who wants to follow after Mr. Oliver and Mr. Land by the fine technique which they have worked out. The apparatus shown in Fig. I is extremely simple to work. One thing about it which surprised me was the way in which the silica tube stood up to the taking of six or seven readings in the space of 60 sec. You have there what is rather a difficult problem. The silica tube must have a thin wall, so as to get a quick response from the thermocouple; but the material is very soft at those temperatures, and the movement about in the bath, and particularly the lateral movement, would tend to bend the silica. As it happens, however, everything has turned out fortunately, and the whole problem is much simplified by the technique which has been evolved.

I hope that we shall have more papers on the lines of that by Mr. Oliver and Mr. Land, dealing with temperature distribution in the furnace. Other people, for special purposes, are measuring from time to time temperatures in the launder stream, in the ladle and in the ladle stream—I happen to know that that investigation is proceeding now—and also in the trough, and perhaps in the mould itself. All those measurements are no doubt useful in themselves, but I think that their value would be considerably increased if they were pieced into one complete picture. In other words, will it be possible at some future time—perhaps not under war-time conditions—to make a detailed study of easts right through from beginning to end? If so, I think that we shall obtain a complete picture which will greatly assist in the solution of the difficult problem of control.

Dr. E. Gregory (Hon. Member of Council; President, Sheffield Metallurgical Association): I regret that I have not had time to read these two papers in detail. Moreover, with the exception of one smaller furnace, all our furnaces at Park Gate are basic openhearth, and there have been, as Members of the Sub-Committee well know, some difficulties in connection with the use of the immersion thermocouple with basic slags, although these have apparently been almost completely overcome by the use of the graphite end.

Dr. Desch has mentioned the question of the influence of emissivity factors on optical-pyrometer temperature-readings. I may say that members of my staff regularly take optical-pyrometer readings on the casting stream as it issues from the ladle, but, frankly, I have little confidence in the recorded results; the emissivity factors vary too much, owing to polarisation effects, fume, the chemical composition of the steel, &c., and if one adds 120° or 125° C. to the indicated readings, as is usual to convert, supposedly, indicated into true temperatures, it does not really mean

anything at all; but I do like to have the optical readings taken, because I think that the furnacemen, when they see someone looking through a temperature-measuring instrument, think that this is a check on their practical judgment. We certainly intend, in the very near future, to use the immersion thermocouple, and I hope that we shall get some real practical information and benefit from it.

One disturbing feature to me, at the moment, is the question of temperature gradients in baths of molten steel. I venture to suggest to Mr. Oliver and Mr. Land that \pm 20° C. is not nearly a sufficiently narrow range of accuracy; \pm 20° may mean all the difference between a cold cast and a hot cast. Much attention has been devoted during recent years to the physical chemistry of steelmaking, but when I learn of the results given in Mr. Oliver and Mr. Land's paper I wonder what credence can be attached to the values of the velocity coefficients and equilibrium constants for the reactions that occur in molten steel which have been quoted, both here and abroad. I am certain, however, that further refinement and greater accuracy are possible, and with this refinement we should be in a better position to determine these equilibrium constants and velocity coefficients more accurately and place steelmaking on a more scientific and truly physico-chemical basis.

Mr. Oliver and Mr. Land are to be congratulated on an important contribution to the literature of the determination of steelmaking temperatures and it is hoped that their experiments

will be continued.

Dr. G. B. Waterhouse (Massachusetts Institute of Technology, Cambridge, Mass., U.S.A.), who was received with applause, said: If I may, I should like to make a few general remarks before coming to the papers under discussion. In a way, I am representing the steel men of America at this Meeting. Every man in our plants and our laboratories envies me for being here. We think that the chance of attending an Annual Meeting of this Institute is almost like going to heaven, because we read the proceedings of this Institute with a great deal of interest, and we read the discussions with about twenty times more interest, because we have the feeling, somehow, that in your discussions "the lid is off," and that when a man gets up to discuss a paper here he really says what he feels, which is not always the case in the technical meetings in our country. I am speaking, therefore, for a tremendous number of men on our side in saying how glad I am to be here, and particularly in saying how much I admire the fact that, notwithstanding the war, you are keeping this work going. It is very agreeable to think that you are maintaining the continuity of this very old Institute, whatever the conditions and the difficulties may be.

As for the two papers now before us, we are all going to be very much indebted to you for what you have done. As Dr. Desch

and others have said, the development of a method of determining accurately the temperature of steel in steelmaking processes is not an easy thing. We have devoted a great deal of effort on our side to this question, and we have thought from time to time that we had solved it. We had an immersion method—not a thermocouple exactly—of determining temperatures which we tried with great perseverance, and which has given us results which have been of great value, but I do not think that the results on the whole have been so successful as these. We are very happy that you are working something out which we shall, I am sure, try, to see what we get.

I should like to know the greatest depth of slag which has so far been encountered; because, of course, the application of this method in our case will be to basic furnaces and not to acid furnaces, and particularly to basic electric and basic open-hearth furnaces. There the questions which have been briefly mentioned this afternoon are of very great importance to us. To determine the temperature gradient vertically will be of importance, but of far greater importance to us will be the so-called horizontal divergencies, because our furnaces are big, as of course yours are also, and we have an idea that our temperatures vary a great deal over the length and the breadth of the bath as well as over the depth.

Finally, I should like to mention a very important practical application of this kind of work. I cannot go into it in detail, because of war conditions; but we have an application where we melt steel in high-frequency furnaces, and we use that molten steel to produce an object of very great importance in the ordnance programme. To make that thing work, we must know very accurately the temperature of the molten steel, and we have had to use a platinum thermocouple, in our case protected by a silica tube, as being the only method which was available, and it has been the one thing which has made at any rate the steelmaking end of the process a success. I have been in very close touch with that particular development. We use a silica covering to the thermocouple which comes from this country. We do not know what we are going to do when we cannot get that silica thermocouple, because so far we have not been able to develop a suitable silica covering for our needs. We have there, without the slightest doubt, a very important application for this kind of thing.

JOINT CORRESPONDENCE.

Dr. W. H. HATFIELD, F.R.S. (Vice-President; Brown-Firth Research Laboratories, Sheffield), wrote: I have read the paper by Mr. Oliver and Mr. Land with very much interest, and think that it is a valuable contribution from the standpoint of the ex-

ploitation of the progress that has taken place as a result of the efforts of the Liquid Steel Temperature Sub-Committee to produce adequate means for measuring the temperature of liquid steel. With the collaboration of my colleague, Mr. E. Ward, I, too, have very thoroughly tested out the possibilities of the employment of the Schofield modification of the thermocouple pyrometer. The actual experiments made in the Firth-Brown Works produced data of sufficient interest now to be put forward, with a view to amplifying the data already so excellently presented in the paper by the authors.

With a view to obtaining information regarding the bath temperature distribution of various types of steel-melting furnaces, experiments were carried out on heats made in the following furnaces:

- (1) Siemens acid open-hearth. Capacity 90 tons. Furnace
- (2) Basic electric arc, 3-electrode. Capacity 10 tons. Furnace E8.
 - (3) High-frequency. Capacity 10 cwt. Furnace HF12.

From these tests it was hoped to gain useful data on the following points :

- (a) Temperature distribution at various positions across the bath, and at different depths, generally three, this latter being the main feature of the explorations.
 - (b) Temperature distribution at various stages of the heats.
 (c) Effects of rabbling on the bath temperature distribution.
- (d) The possibilities of temperature control by use of the immersion pyrometer.

Immersion thermocouples of the Schofield-Grace type were used, temperature measurements being made on a portable potentiometer, the scale of which could be read with ease up to 2° C.

Siemens Acid Open-Hearth Furnace. (Table A, Fig. A.)

The thermocouples used during the investigations on this furnace were housed on wheeled carriages, two of which were available. The procedure generally adopted was to make one immersion in the centre of the bath with one thermocouple, followed immediately by an immersion with the second thermocouple in a different part of the bath. These two immersions were repeated at various stages of the heats, and in most cases temperatures were measured at three depths during each immersion. It was hoped by adopting this procedure to gain some indication of the bath temperature distribution, using the centre readings (a position in the bath likely to be used for routine control) as a reference point against the other positions. Throughout the heats tempera-

ture measurements were taken at a depth of 4 in. min. and 18 in. max. in baths of steel approximately 24 in. deep. The time taken over the two sets of determinations, with two exceptions, was 2–3 min. It was thought that little or no change in temperature would take place at the depths concerned during this period, and so allow of comparison between the two sets of readings. The exceptions were attempts to take three sets of readings, when the time taken was about 4 min.

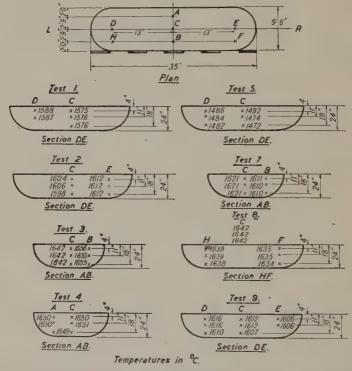


Fig. A.—90-Ton Siemens Acid Open-Hearth Furnace A. Bath temperature distribution.

Remarks.—Tests 1, 2, 3 and 4 show that during the boil the bath was very uniform at each position at all depths. Comparing position C horizontally with other points at corresponding levels, the maximum difference in any one test shows position C to be 13° C. lower at 4 in. (test 1), 13° lower at 11 in. (test 3) and 14° lower at 18 in. (test 2).

From the remaining tests, 5-9, which were carried out on a different heat, it will be noted that when melted (test 5) the metal

Table A.—90-Ton Siemens Acid Open-Hearth Furnace A.

Depth. In.							111	4 11 18
Temp.							1635 1635 1634	1606
Position.*							F. F.	E
Depth. In.	4 11 18 4	1187	184 18	4 11 0		4118	34118	4 111 18
Temp.	1588	1612	1655 1655 1650 1650 1649	1486		1611	1639 1639 1638	1616 1616 1610
Position.*	D	A	A A	p {		B	H	D {
Depth. In.	4.11.4	1184	188	411	2 4 E 2	4 11 8	4 11 8	111
Temp.	1575 1576 1576 1604	1606	1642 1642 1650 1651	1492	1614	1621	1642 1642 1642	1612 1612 1607
Position.*	0	0	0 0	0	0	O	0	0
Bath Condition.	Commence boil. 11 min. after feed. Gas L to R. Boil. 8 min. after		feed. Gas R to L. Boil. 25 min. after feed. Gas R to L.	Melted. Gas R to L .	Before lime. Gas R to L .	Before ore. Gas L to R .	Boil, 12 min, before commence finishings,	Gas. L. to R. Bath Gas. L to R. Gas. L to R.
Time from Melt.	42 min.	2 hr. 29 min.	3 hr. 38 min.	0	1 hr. 17 min.	2 hr. 4 min.	6 hr. 25 min.	7 hr. 21 min.
Test No.	- 6	1 m	4	10	9		œ	6

See Fig. A

at position C was 20° cooler at 18 in. than at 4 in., whilst at posi-

tion D there was a difference of only 4° C.

Comparing the ends of the bath, the maximum variations between any set of figures are 5° , H and F (test 8), and 10° , D and E (test 9), the right end of the bath being cooler in each case, although the gas flow was from right to left in test 8 and left to right in test 9. In test 9 it was possible to make only two observations at position E, as approximately 6 in. of metal had run out of the bath during tapping.

Basic Electric Arc Furnace (3-Electrode Héroult Type). (Table B, Fig. B.)

The procedure adopted for investigations in this type of furnace

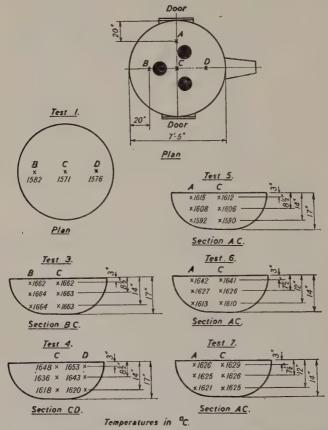


Fig. B.—10-Ton Basic Electric Arc Furnace (3-electrode Héroult type) E8. Bath temperature distribution.

Table B.—10-Ton Basic Electric Arc Furnace (3-Electrode Héroult Type) E8.

Teach Not								
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	Depth. In.	က				man man i man i		
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Temp.	1576						
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	Position.*	D						į
Bath Condition. Position.e Temp. Depth. Position.e Tabbled. Depth. Position.e Tabbled. Depth. Dept	Depth.	ಣ		3 84 14	8 4 4	8. 14. 14.	3 71 12	3 12 12
Bath Condition. Position.e Temp. Depth.	Temp.	1582		1662 1664 1664	1653 1643 1690	1615 1608 1592	1642 1627 1613	1626 1625 1621
Bath Condition. Posttion.* Temp. rabbled. Not C 1571	Position.*	В		B	D	A	A	A {
Clear melt, Not rabbled. 25 min, after commediately prior to slagging. Not rabbled. Before additions. Not rabbled. Immediately prior to capping. Not rabbled. Refining. After period of 20 min. Of Rabbled. Refining. After period of 20 min. Of Rabbled. Refining. After period of 20 min. Of Rabbled. Immediately after period of 20 min. Of Rabbled. Refining. After period of 20 min. Of Rabbled. Immediately after abbled.	Depth. In.	ಣ	es ∞ 4.	3 84 14	es ⊗ 4	14 8 1 4 1 4 1 4 1 4 1 4 1 4 1 4 1 4 1 4	3 12 12	12 A
Clear melt, Not rabbled. 25 min. after commence boil. Not rabbled. End of boil. Immediately prior to slagging. Not rabbled. Immediately prior to rabbled. Immediately prior to rabbled. Immediately prior to to tapping. After period of 20 min. quiescence. Not rabbled. Refining. After period of 20 min. quiescence. Not rabbled. Immediately after period of 20 min. quiescence. Not rabbled. Immediately after period of 20 min.	Temp.	1571	1634 1634 1634	1662 1663 1663	1636	1612 1606 1590	1641 1626 1610	1629 1626 1625
Clear melt, rabbled. 25 min. at mence be rabbled. End of by mediately slagging. rabbled. Before add Not rabb. Immediate to tappin Rabbled. Refining. riod of quiescenc rabbled. Refining. riod of quiescenc rabbled. Immediate to tappin Rabbled. Immediate to tappin Rabbled. Immediate rabbled. Immediate rabbled.	Position.*	0	O	0	0	0	0	0
uime from 10 0 35 min. ur. 30 min. ur. 38 min. ur. 51 min.	Bath Condition.		25 min. after commence boil. Not rabbled.	End of boil, Immediately prior to slagging. Not rabbled.	Before additions. Not rabbled.	Immediately prior to tapping. Rabbled.	Refining. After period of 20 min.	Immediately after above, well rabbled
T	Time from Clear Melt.	0	35 min.	1 hr. 30 min.	3 hr. 38 min.	4 hr. 51 min.	:	:
, c.	Test No.	-	c1	က	4	20	9	7

* See Fig. B.

was exactly the same as for the acid open-hearth, excepting that

the thermocouples were lifted into the furnace by hand.

In baths of steel approximately 14 in. and 17 in. deep, temperatures were measured at varying depths up to 14 in., excepting in test 1, where a single reading was obtained at each of three points across the bath at a uniform depth of 3 in., one thermocouple being used for this test and moved from point to point. During all the immersions the electrodes were raised.

Remarks.—Figures obtained during and at the finish of the boil (tests 2 and 3) show the temperature of the bath to be very uniform. During periods other than the boil, on baths not rabbled, there is a vertical temperature gradient of about 30° between 3 in. and 14 in. depth, whilst, comparing position C horizontally with points at corresponding levels, the maximum difference in any one test shows position C to be 11° lower at 3 in. (test 1), 7° lower at $8\frac{1}{2}$ in. (test 4), and 4° higher at 12 in. (test 7).

Tests 6 and 7 were carried out on a different heat, and measurements taken both before and immediately after rabbling clearly show its effect in a furnace of this size. The rabbling in test 5, with 2-3 in. more metal in the bath, was not quite so effective, and the vertical temperature gradient, as compared with test 7,

was much greater.

High-Frequency Furnace. (Fig. C.)

For testing the uniformity of the bath temperature distribution in the high-frequency furnace two thermocouples were used. These

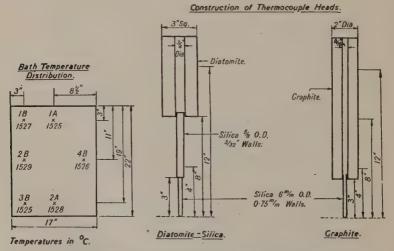


Fig. C.—10-Cwt. Basic High-Frequency Furnace HF12. Bath temperature distribution and construction of thermocouple heads.

consisted of a main silica tube $\frac{5}{8}$ in. in dia., strengthened with a coating of refractory cement, making a total outside diameter of approximately $\frac{3}{4}$ in. A $4\frac{1}{2}$ -mm. bore silica tip was cemented in to receive the hot-junction end of the thermocouple, the tip protruding for about 3 in. from the main tube.

The two thermocouples were immersed simultaneously into a bath of steel about 22 in. deep, just prior to tapping, and after the current had been switched off from the furnace. Two measurements were made with thermocouple A in the centre of the bath:

 $1A:1525^{\circ}$ C. at 3 in, depth followed by—2A: 1528° C. ,, 19 in, depth.

The time taken to make the observations was 20 sec.

Thermocouple B was immersed about 3 in. in from the edge of the furnace lining, and readings were taken in the following order:

1B: 1527° C. at 3 in. depth. 2B: 1529° C. ,, 11 ,, 3B: 1525° C. ,, 19 ,, 4B: 1526° C. ,, 11 ,,

For observation 4B the thermocouple was raised from the 19 in, depth at 3B and placed in a corresponding position to 2B in another part of the bath, in order to avoid the possibility of recording a low reading, due to cooling effects from the silica sheath, in the original position at 2B. During this test 40 sec. were required to make the four observations.

Remarks.—The bath would appear to be uniform to within 5° , with perhaps a tendency to a slight increase in temperature towards the middle and bottom. A decrease in temperature of 3° was noted between positions 2B and 4B, the measurement at 4B being taken about 30 sec. after that at 2B.

Accuracy of Temperature Measurements.

In all the tests platinum/platinum-10%-rhodium thermocouples were used, and, as previously stated, measurements were made on a portable potentiometer which could be read with ease up to 2° C. and estimated to 1° C.

The greatest total immersion time for any one of the several thermocouples used throughout all the tests was 144 sec. After the tests this couple was checked against a new unused thermocouple and was found to agree to within 3° C. For this check the two couples were threaded through a single four-bore silica insulator, the whole being mounted in the same thermocouple head, with both hot junctions protruding into a single 4.5-mm. bore silica sheath. The check immersion was carried out in the bath of a high-frequency furnace.

Observations at different depths were taken successively from

the top downwards, in order to avoid cooling effects of the graphite

rod on the surrounding steel.

The portion of thermocouple immersed in the steel during the open-hearth and electric-furnace tests was protected by a graphite rod 20 in. long \times 2 in. in dia., and a 4·50-mm. inside dia. \times 6·0-mm. outside dia. silica sheath was cemented in at the hot-junction end.

It was thought that the immersion of the graphite rod into the steel might cause local cooling and so depress the readings. In order to investigate this possibility a thermocouple was mounted in a head constructed from a diatomite block and silica tubes, as shown in Fig. C, and tested against one of the graphite type. This latter was first immersed in an open-hearth bath during the boil, three readings being taken at different depths. Within a minute the immersion was repeated with the diatomite-silica type in approximately the same position of the bath. The results obtained show that the maximum discrepancy that could be expected would only be 2°:

Graphite-Rod Type.	Diatomite-Silica Type.
1616° C. at 4 in.	1618° C. at 4 in.
1616° C, 8 .,	1618° C. " 8 "
1616° C. " 12 "	1618° C. ,, 12 ,,

Taking all sources of error into account, the observations made on a single immersion at three depths should be comparable to within \pm 1° C., whilst from point to point where different thermocouples were used it is considered that the maximum error would be no greater than \pm 4° C. and, in the majority of cases, probably less.

Dr. R. V. Riley (Darlaston) wrote: While working with the Schofield quick-immersion pyrometer in an acid open-hearth steel furnace, it was frequently noted that during the passage of the thermo-junction through the slag, the temperature recorded by the potentiometer indicator was momentarily 20°-30° C. higher than later when the thermocouple was completely immersed in the metal. The opportunity did not present itself to examine the phenomenon further, and it is not known whether the reading was true or whether it was due to the over-swing of the galvanometer needle.

From their wide experience of liquid steel temperature measurement, the Liquid Steel Temperature Sub-Committee may be able to say if at any time during the refining process the slag is, in fact, 20–30° C. hotter than the metal. If such appreciable differences in slag and metal temperatures are possible it would

imply:

(1) That a knowledge of the temperature of the slag in addition to that of the metal would be necessary in order to examine quantitatively the effect of temperature on the rate of chemical reactions in the steelmaking process.

(2) That the slag temperature would probably be at least as important as the metal temperature to the furnaceman, who may, in consequence, be able to prolong the life of the furnace linings.

Mr. D. Manterfield (Messrs. Steel, Peech & Tozer, Sheffield) wrote: I think it will be appreciated from the Sub-Committee's Third Report that considerable progress has been made in the measurement of liquid steel temperatures. Whilst the technique may still be in a process of evolution, it can be said that we have passed the purely experimental phase. It now remains to make practical use of the instrument, which is the ultimate aim of the work that has been, and is being, done. In order to do this, some knowledge must be gained of the influence of temperature upon the subsequent properties of steel and a range of temperatures determined which will give these properties. Finally control must be exercised to obtain these desired temperatures.

This was part of the Sub-Committee's programme, and some

progress has been made since the Report was issued.

At the firm with which I am associated, investigations have been made into this problem. With acid open-hearth steel, 130 casts of alloy steels were examined, and the physical properties, as indicated by the percentage of forgings passing the mechanical tests without retreatment, were correlated with the tapping temperature. This examination revealed that a range of 1610–1630° C. gave the largest percentage of forgings passing this test. Further, 600 casts of basic open-hearth steel were examined and grouped according to their qualities and subsequent processing. The melting points of the different types of steel were calculated on the basis of the work of Roeser and Wensel.¹ From this the degree of superheat was ascertained and plotted against the "sold yield" (i.e., the total yield of first-quality material from the ingots rolled). This yield is taken as a good general indication of steel quality.

There was a very definite correlation between these, and it was possible to fix a range of temperatures giving the optimum yield on this basis. This range varies from 1600–1625° C. for very low carbon to 1540–1565° C. for 1% carbon steels, with variations for alloy and special qualities. Control is now being exercised as a

result of these findings.

With regard to Mr. Oliver and Mr. Land's paper on temperature distribution, this is a very important aspect of the subject. Our experience in both the acid and the basic open-hearth confirms the findings of the authors. In the large majority of cases we feel that a temperature taken under normal conditions at the standard position is a true indication of comparative temperatures, the error from all sources being not greater than $\pm\,10^{\circ}$ C. However,

¹ W. F. Roeser and H. T. Wensel, Journal of Research of the National Bureau of Standards, 1941, vol. 26, Apr., pp. 273–287.

temperature gradients can be built up, not only after the bath is quiescent, but as the heat is building up. A few cases have been noted where a preliminary temperature measurement half-an-hour before tapping was below the minimum specified, but a further measurement taken immediately before tapping showed an increase of 20–25° C., bringing it within the specified range.

These few charges have shown small amounts of skull in the ladle, indicating a rather low temperature. It would appear, therefore, that insufficient time had elapsed for the heat to penetrate to the lower regions of the bath and a temporary gradient had

been set up under these conditions.

It is hoped to follow up the admirable work of Mr. Oliver and Mr. Land on larger basic open-hearth furnaces at these works.

SUB-COMMITTEE'S AND AUTHORS' REPLIES.

The Sub-Committee, in reply, wish to express their appreciation of the way in which their Third Report has been received, and are greatly encouraged by the kind remarks made by the contributors

to the discussion on the work of the Sub-Committee.

As a means of temperature measurement of liquid steel under practical conditions, the optical pyrometer must now be considered as superseded by this improved quick-immersion thermocouple technique. But it must not be inferred from this that optical methods should be abandoned as a means of measurement and control. There is no doubt whatever that the disappearing-filament type of optical pyrometer, which is unaffected by polarisation, has provided data of practical significance, enabling better control to be exercised than before its use. It has, of course, long been realised that its indications are dependent on factors other than temperature alone, but it is only comparatively recently that the variation in emissivity has been investigated, which is probably the main factor apart from lack of calibration. While the emissivity factor of 0.4, recommended by Burgess in 1917, can still be regarded as a representative average for molten steels, it is now fairly well established that the factor may vary, not only from steel to steel, but over a range of temperature for any one steel. Its determination may be of practical value, and, in conjunction with accurate temperature measurement, enable improved control to be obtained. Improved apparatus and technique are now being developed, and a comprehensive scheme of future work has been devised.

The Sub-Committee welcome very much the interesting remarks of Dr. Waterhouse, especially with reference to the methods which have been developed in America, and they will be only too pleased to co-operate as far as possible. In reply to the question raised by Dr. Waterhouse regarding the greatest depth of slag so far encountered, this would be about 9 in. in basic open-hearth furnaces,

although the average depth would be considerably less than this. The routine measurement of temperatures in 87-ton fixed basic furnaces is carried out without any difficulty under various types and depths of slag. The introduction of the graphite end block

completely solved the past troubles with basic slag.

Dr. Riley raised an interesting point regarding slag temperature. It is pointed out that Mr. Oliver and Mr. Land noted in their paper an instance where a recorded temperature 20° C. higher than that of the metal was indicated as the couple was withdrawn through the slag. The Sub-Committee have proposed to include slag temperature determinations in a future survey when a graphite sheath might be employed in basic slag. Although no other actual measurements have been published. Dr. Rilev's observation is fully confirmed by the experience of the Sub-Committee, in that a difference of temperature is frequently set up between the slag and metal. It is suggested that temperature gradients then extend through the slag and metal, the upper surface of the slag being hotter, owing to its proximity to the flame. If the gas is slackened owing to an excessive temperature in the bath it is probable that the upper surface of the slag will then temporarily be cooler than the metal. It is further suggested that at the slag-metal interface in the reaction zone, the temperature of the slag and metal would be practically identical. The recorded metal temperature should therefore be of sufficient accuracy for any physico-chemical investigations. However, slag temperatures themselves would be useful additions to any thermal data acquired in investigations, and would be specially useful in assessing the effect of temperature and slag attack on refractory life.

The Sub-Committee are interested to learn that Mr. Manterfield was able to correlate the quality of the steel with its temperature during manufacture. The examples given of casts which left skull in the ladle in spite of the fact that the temperature immediately before tapping was normal, appear to indicate the importance of taking temperatures during the course of each heat. Used intelligently in this way, the quick-immersion pyrometer can be effective in the

successful manufacture of steel.

Mr. OLIVER and Mr. Land replied: We very much appreciate the encouraging and complimentary remarks of Dr. Desch, Dr. Schofield, Dr. Gregory and Dr. Waterhouse, which confirm our impression that the subject under investigation is generally worth-

while and of real practical value in wartime.

Several references were made to the question of accuracy, and a few further remarks on the subject are desirable. It is necessary to distinguish clearly between the sensitivity of the method and the accuracy of the observations. The sensitivity depends chiefly on the measuring instrument, and with a good potentiometer should be within \pm 1° C. Differences of temperature measured with the

same thermocouple should certainly be significant to $+2^{\circ}$ C., but when different thermocouples are used errors of $\pm 4^{\circ}$ C. might arise. When the accuracy of a single observation is in question the variation of thermocouple characteristics, possible errors in instrument calibration and the uncertainty of the original calibration of the thermocouple in terms of the International Temperature Scale make limits of \pm 5° C. necessary. The present paper is concerned with the use of a single observation of temperature as a measurement of the mean bath temperature. We concluded from our observations that with the bath on the boil an accuracy of $+5^{\circ}$ C, was obtainable. However, when the gas evolution had become small in the final period before tapping, a single observation could not be relied upon to better than $\pm 10^{\circ}$ C., and under very unfavourable conditions the uncertainty might amount to $+20^{\circ}$ C. Where this range of uncertainty still appears to be too great it could probably be reduced to one half by following the recommendation, made at the end of the paper, of making several measurements at two or more locations in the bath and thus arriving at a more representative figure.

We concur with Dr. Gregory's opinion that little credence can be attached to some of the past published work on high-temperature investigations, owing to severe limitations on the accuracy of

the temperature determinations.

In reply to Dr. Desch, we agree that the exploration of temperature distributions will probably figure more in the future, especially when new methods are applied to the more direct control of steel melting. Closer limits of accuracy could certainly be quoted if several nearly simultaneous measurements at different locations were taken, and if comparative readings only are required under comparable conditions it may be possible to achieve determinations

significant to within \pm 5° C.

Dr. Schofield's remarks are gratifying, on account of his unique contributions in this field of investigation. We hope to extend our work on the lines outlined by him, and already one cast of steel has been tested for temperature in the furnace, in the launder and in the casting stream from the ladle. As Dr. Schofield predicts, the value of the individual measurements is markedly enhanced by coordination. Investigations of this type are being undertaken by the Foundry Steel Temperature Sub-Committee for the Steel Castings Research Committee, and data should be available in due course.

The contribution of Dr. Waterhouse is most welcome, and an outline of the state of the art in the U.S.A. is of considerable interest to many in Great Britain. We agree that, so far as temperature distribution effects in large basic open-hearth furnaces are concerned, it may well be that greater differences than those recorded in the present paper will ultimately be found. It is hoped that the existing technical co-operation between the U.S.A. and Great Britain will be strengthened by the visit of Dr. Waterhouse, and that in due course

some of the American investigations to which he refers may be made available to British workers.

We are encouraged by Dr. Hatfield's valuable data and by his appreciation of the results given in the paper. Dr. Hatfield's results not only extend the scope of the distribution investigation, but provide as well an independent check on our survey of the 10-ton basic electric arc furnace. The new data therefore merit close attention

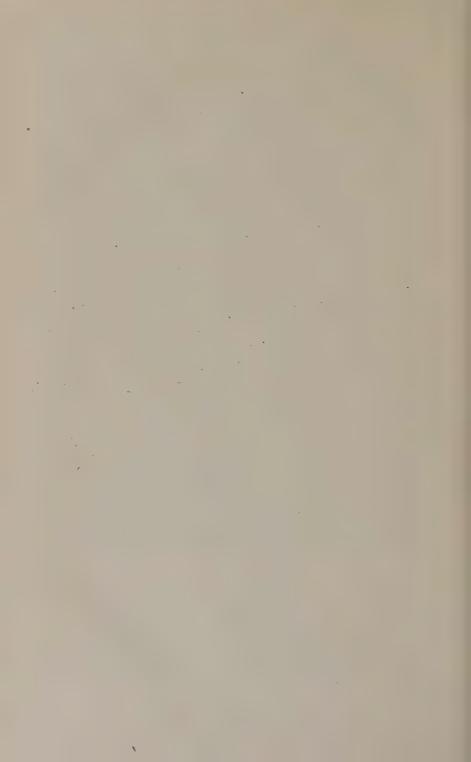
and comparative analysis.

The survey of the 90-ton acid open-hearth furnace is particularly welcome, as it extends the scope of the investigation to the larger type of furnace. It is interesting to find that, when the bath was on the boil, the vertical temperature distribution was again very uniform. This observation is in line with the results on smaller furnaces. As might have been expected, the horizontal variation increased with the size of furnace, but it is reassuring to find that the variation did not exceed 15° C. under the conditions of the

experiments.

We are glad to have an independent check on a 10-ton basic electric arc furnace similar to the one that we surveyed. In comparing the results it should be borne in mind that our furnace was rather deeper than that which Dr. Hatfield chose. A comparison of Fig. 6 and Fig. B reveals the excellent agreement between the two surveys. With the bath on the boil the vertical variation was less than 2° C., but when the bath was quiescent differences of up to 30° C. were found, depending on the effectiveness of rabbling. The agreement on the horizontal variation is equally apparent. The observations on the bath before rabbling are most interesting. They suggest that fairly consistent gradients of 30° C. per foot may be expected in this type of furnace. These gradients account for the very low temperatures which have been measured occasionally at the bottom of the bath after rabbling.

In reply to Mr. Manterfield, we are very pleased to learn that he hopes to survey the temperature distributions in large basic openhearth furnaces. When such data become available it will be possible to get a preliminary bird's-eye view of the temperature distribution of steel melting furnaces in general, which will assist in planning closer controls. It is also gratifying to learn that Mr. Manterfield's experiences with large furnaces are in agreement with the general conclusions which we had drawn for smaller furnaces.



FIRST REPORT OF THE STANDARD METHODS OF ANALYSIS SUB-COMMITTEE 1

OF THE COMMITTEE ON THE HETEROGENEITY OF STEEL INGOTS.2

Paper No. 11/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Standard Methods of Analysis Sub-Committee).

SUMMARY.

In this First Report the Members of the Sub-Committee recommend methods that they have devised, from both theoretical considerations and practical experiments, for the determination of

sulphur and of phosphorus in carbon steels.

The recommended method for sulphur is a refinement of the gravimetric aqua-regia/barium-sulphate process, and for the determination of phosphorus the Sub-Committee recommends a modified bromide process, whereby arsenic is eliminated before precipitation of the phosphorus as the yellow precipitate, as nearly all commercial steels contain arsenic.

Precise details of analytical procedure are laid down, and notes are appended drawing attention to the precautions needed to ensure reproducible results within the specified degree of accuracy expected

when all practical instructions are rigidly adhered to.
In the case of both elements, the Sub-Committee is unanimously of the opinion that the recommended methods cannot be expected to yield consistent results closer than $\pm 0.0015\%$ to the true sulphur

and phosphorus contents of the steel.

It is emphasised that the methods recommended were devised primarily for "referee" purposes, and, therefore, little cognisance was taken of the time or expense involved in the determination of either element. The main object was to devise standardised processes yielding comparable results when carried out by different chemists using the same samples of steel.

The Report concludes with a recommended method for the determination of lead in steel. This method, based on the separation of the lead as lead sulphate and conversion to lead molybdate, was rigorously tested, and remarkably close agreement was obtained.

Introduction.

The need of establishing standard or recommended methods for the analysis of steel was first raised by the British Standards Institution and, later, considered by a Committee of iron and steel makers' representatives of that Institution, under the Chairmanship

¹ Received March 5, 1942.

² A Joint Committee of The Iron and Steel Institute and The British Iron and Steel Federation, reporting to The Iron and Steel Industrial Research Council.

of Sir William Larke, K.B.E. At the latter meeting, strong views were expressed regarding the accuracy of existing methods of analysis, upon the results of which casts of steel were liable to rejection, particularly when made in acid-lined open-hearth furnaces, and it was decided to refer the matter to the Committee on the Heterogeneity of Steel Ingots of The Iron and Steel Institute, with a request that this Committee should set up a Sub-Committee of qualified metallurgical chemists to review existing methods and devise standard reliable processes.

Accordingly, the matter was considered by the Ingots Committee at its meeting on September 22nd, 1939, when it was decided to form the Standard Methods of Analysis Sub-Committee. The

present membership is constituted as follows:

Dr. E. Crossoner (Chairman)	The Park Gate Iron and Steel Co., Ltd.
Dr. E. Gregory (Chairman) . Mr. S. L. Archbutt .	
	The National Physical Laboratory.
Mr. B. Bagshawe	The Brown-Firth Research Laboratories.
Dr. D. Binnie	The Lancashire Steel Corporation, Ltd.
Mr. W. F. Charteris	Messrs. Colvilles, Ltd.
Dr. H. E. Davies (Secretary) .	The Park Gate Iron and Steel Co., Ltd.
Dr. C. H. Desch, F.R.S.	The Iron and Steel Industrial Research Council.
Dr. B. S. Evans, M.B.E., M.C.	The Research Department, Woolwich.
Mr. R. A. Hacking	Messrs. Dorman, Long & Co., Ltd.
Mr. Vernon Harbord	Messrs. Riley, Harbord and Law.
Professor R. D. Haworth .	Sheffield University.
Mr. B. W. Methley	Messrs. Steel, Peech and Tozer.
Mr. N. D. Ridsdale	Messrs. Ridsdale & Co., Ltd.
Mr. T. E. Rooney	The National Physical Laboratory.
Mr. M. C. Sanders	Messrs. Guest Keen Baldwins Iron and
	Steel Co., Ltd.
Mr. A. Scholes	Messrs, Pattinson and Stead.
Dr. T. B. Smith	Sheffield University.
Mr. W. W. Stevenson	The United Steel Companies, Ltd.
Dr. H. Sutton	The Royal Aircraft Establishment,
	Farnborough.
Mr. E. J. Vaughan	The Naval Ordnance Inspection Labora-
1	tory, Sheffield.
Mr. G. C. Waite	3.5 7.7 7.331 0.01 7.3
Mr. T. R. Walker	English Steel Corporation, Ltd.
Mr. J. L. West	Messrs. Hadfields, Ltd.
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At first, the work of the Sub-Committee was directed to the standardisation of methods for the determination of sulphur and phosphorus in carbon steels, and four "standardised" steels were circulated for analysis, members being requested to determine the two elements by their own usual laboratory methods. In submitting the results, members were requested to give full details of the methods employed.

It was soon evident that, although most of the methods were based on similar general principles, there was a woeful lack of uniformity in regard to detailed analytical procedure. Thus, in the determination of sulphur by the gravimetric process, some members used potassium nitrate to fix the sulphuric acid during baking, others used potassium chlorate, potassium bromide or sodium carbonate, and some members used no reagent whatever to ensure this fixation. Widely different ratios of nitric and hydrochloric acids were used by different chemists and the quantities of hydrochloric acid added to the baked residue and for the adjustment of the final acid concentration of the solution from which the sulphur was finally precipitated showed considerable variation. Some of the firms represented did not use the gravimetric process for the determination of sulphur in carbon steels, but, instead, preferred evolution processes. Here, too, uniformity was lacking in the technique of the methods employed, particularly in regard to the absorbent for the liberated hydrogen sulphide and the concentrations of the solutions employed in the final titrations. The conditions under which the titrations were carried out varied greatly.

In regard to phosphorus, the conditions were equally chaotic. Very few of the methods described made attempts to remove any arsenic present before precipitation of the phosphorus, and even in those methods where this was supposed to have been done, subsequent work by the Sub-Committee clearly proved them to be unsatisfactory. In two instances the yellow precipitate was weighed as such, in one case by brushing the dried residue from the filter paper on to the balance scoop. Apart entirely from the fact that this introduces an undesirably high factor, this finish is clearly unsatisfactory. In all the other processes, precipitation of the phosphorus was made in the presence of arsenic, but the conditions in regard to solution of the steel and precipitation of the phosphomolybdate were widely different, particularly with reference to the nature and strength of the molybdate precipitant. Most members of the Sub-Committee favoured the volumetric finish, whereby the yellow precipitate is dissolved in standard sodium hydroxide solution and the resulting solution is titrated to neutrality by means of standard alkali and acid solutions in the presence of a suitable internal indicator. In regard to standardisation of the acid and alkali solutions, some members used "standard" phosphorus steels; others used A.R. sodium carbonate to standardise the acid and alkali solutions, and one member advocated benzoic acid for this purpose. Benzoic acid can be obtained in a high degree of purity and the members of the Sub-Committee have since strongly recommended its use as a basis of standardisation for acidimetric and alkalimetric processes generally.

From the foregoing it will perhaps be realised that the primary object of the initial experiments was to obtain a comparison of the results produced by methods which were known to differ in many essential details and principles. The results reported were in fairly good agreement, taking account of the fact that they were obtained by different analysts having their own ideas of laboratory technique, but they were definitely not good enough for "referee"

purposes. In the cases of both sulphur and phosphorus, one of the main causes for the discrepancies appeared to be in the use of "standard" steels. It was suggested that the stated sulphur and phosphorus contents of these standard steels were open to question, thus constituting a major source of error when used in the assay of steels of unknown sulphur and phosphorus contents. Subsequent experiments, however, proved that errors due to this source were considerably less than had first been anticipated.

In the initial experiments it was shown that the evolution methods for low-sulphur steels gave results in fairly close agreement with those obtained by gravimetric and combustion processes, but with steels of higher sulphur contents evolution methods definitely gave low results, a conclusion not altogether unexpected.

Generally, the agreement between the results obtained by different investigators using different methods was not satisfactory, and this at once raised the question as to whether closer agreement would be possible if all the analysts employed the same methods.

THE DETERMINATION OF SULPHUR IN STEEL.

Formulation of a "Standard" Method for the Determination of Sulphur.

From a consideration of the results of the initial experiments it was decided that evolution processes gave unreliable results, and, whilst fully appreciating the fact that such methods may be usefully employed in routine work on carbon steels, provided that due cognisance is taken of the influence of even small proportions of residual elements, the Sub-Committee unanimously decided that the evolution process could not possibly be considered as a basis for the development of a standard method to be recommended for referee work.

The combustion method for sulphur was discussed at some length, but the main objections were that it was not truly stoichiometric and relied for its standardisation on a steel the sulphur content of which had been determined by some other process.

Accordingly, it was decided to concentrate attention on the gravimetric barium sulphate process, even though it was realised that the method bristled with potential sources of error, and a draft process, together with two new standard sulphur steels, was circulated to all members of the Sub-Committee.

The results obtained were most disappointing; the wide divergencies from the mean values were most disconcerting, but they formed a basis for much discussion on analytical technique.

With very low-sulphur steels—say, below 0.02%—opinion was divided regarding the need for the addition of a definite amount of potassium sulphate solution of known strength in order to accelerate precipitation of the barium sulphate, and it was finally decided

not to incorporate this in the general method, but that a note should be introduced indicating that for steels of very low sulphur contents

an addition of potassium sulphate solution was desirable.

The washing of the barium sulphate residue was thought to constitute a possible source of error. In the draft method, six washes had been specified, but it was pointed out that different chemists had different ideas regarding the volume of a "wash" and that it was better to state that washing should be continued until the filtrate became absolutely free from dissolved chlorides.

The whole method was then redrafted, incorporating this and other suggested minor amendments. This further redraft was again circulated, together with further supplies of standard steel millings, and the analytical results obtained are shown in Table I.

Table I.—Sulphur Determinations on Steel G by the Draft "Aqua-Regia" Gravimetric Method.

	Aı	alys	t.		Sulphur. %.					
1						0.044	0.044			
2	• 1					(0.040			
3						0.041	0.041			
4 5			80		0.040	0.040 0.040	0.040	0.041	0.042	
5				. !		. 0	0.0415			
6						. 0	0.042			
7						(0.042			
7 8						0.041				
9						0.0396	0.0388	0.0396		
10						0.041	0.041			
11						0.039	0.039			
12						0.041	0.042	.043		
13						0.041	0.041 0	-041		
14			-1.0			0.042	0.043	.044		
15						0	0.041			
16							0.041			
17		4				0.042	0.042			
	Mean					. 0	0.0412			
	Greatest variation)	+0	0.0028			
	fron	n m	ean.		}	-0	0.0024			

It will be observed that three investigators reported 0.044% and three others a value of 0.039%, *i.e.*, a range of error of 0.005%, which the Sub-Committee considered to be excessive. It was pointed out, however, that the difference between these values indicated the gain or loss of about an eighth of a milligramme of sulphur only, or the equivalent of less than a milligramme of barium sulphate. In order to explain the discrepancies several views were expressed. It was suggested that the instruction "evaporate to a scum" was vague and indefinite, leading to variation in the acid concentration of the solution. It was considered by some that the

final solution, prior to precipitation of the barium sulphate, was too strongly acid, although others indicated that with a much lower acid concentration there was a grave risk of partial hydrolysis of the ferric chloride, resulting in contamination of the barium sulphate

precipitate.

It was generally considered, however, that the main source of error was in the determination of the "blank," since it had been shown that this varied considerably, even when determined by chemists using acids from the same source of supply. It was emphasised that it was vitally important to take the greatest care in regard to stock supplies of the acids used. Winchester quarts of the acids should be reserved exclusively for this purpose, and the use of bench hand-bottles, which were liable to contamination of their stoppers, was to be deprecated.

It was also emphasised that special glassware should be reserved

solely for sulphur determinations.

Some members considered that in the blank determination the acid concentration was somewhat higher than in the actual assay, and that this could be adjusted by evaporation of the blank solution to dryness again, before the final precipitation. It was considered, however, from the accumulated evidence, that the acid concentration was less critical than had previously been supposed.

Other slight alterations to the redraft were made and it was decided to incorporate notes regarding precautions and recom-

mendations.

It was considered that the gravimetric barium sulphate process could not be expected to yield reproducible results within $\pm~0.0015\%$ of the true sulphur content.

Details of the method finally agreed upon are given below.

Recommended "Aqua-Regia" Gravimetric Method for the Determination of Sulphur in Carbon Steels.

Solutions Required.

Dilute Hydrochloric Acid.—Dilute 5 ml. of hydrochloric acid (sp. gr. 1·16) to 100 ml. with distilled water.

Barium Chloride Solution.—Dissolve 20 g. of barium chloride crystals in 100 ml. of distilled water.

Procedure.

Weigh 5 g. of sample, transfer to a covered 600-ml. squat-type beaker, and add 0·1 g. A.R. potassium nitrate crystals. Mix 35 ml. of nitric acid (sp. gr. 1·42) with 25 ml. of hydrochloric acid (sp. gr. 1·16) and, immediately after mixing, cautiously add to the contents of the beaker. When the early violent action subsides, place the beaker on the hot-plate, digest until solution is complete, and evaporate, taking care to avoid spurting.

When the solution is low in bulk, move to a cooler part of the hot-plate and remove the cover-glass. During evaporation turn the beaker through an angle of about 90° at regular intervals, in order that the condensed acid on the cooler side may counteract any tendency towards creeping up the walls of the beaker. In this way the solidified mass is concentrated on the bottom of the containing vessel. Slowly move the beaker towards the hottest part of the plate and bake until no smell of acid fumes can be detected. This baking takes about half-an-hour at a temperature of approximately 300° C. Remove the beaker from the hot-plate and cool on an asbestos pad or mat. Add 40 ml. of hydrochloric acid (sp. gr. 1·16), replace the cover and digest at a temperature just short of boiling until all the iron salts are redissolved.

After complete solution, evaporate strongly to remove most of the excess acid, and then more cautiously until a scum appears on the surface. Allow to cool slightly and add 20 ml. of hydrochloric acid (sp. gr. 1·10), heating gently until a clear dark-brown solution is obtained. Dilute with hot water to 45 ml. and filter immediately through an ashless paper-pulp pad into a 250-ml. conical beaker. Carefully wash the beaker and filter with cold water and dilute hydrochloric acid solution alternately until the total volume of the filtrate is about 100 ml. Add 10 ml. of barium chloride solution, swirl or stir the contents of the beaker and stand

over-night or for several hours.

Filter through a tightly-packed ashless paper-pulp pad, washing the precipitate from the beaker with a jet of cold dilute hydrochloric acid solution containing I g. of barium chloride per litre. Wash until the filter is free from iron salts, and continue washing with cold water until chlorides are removed. Remove surplus water by suction and transfer the pad and precipitate to a platinum or porcelain crucible. Dry the filter pad completely at a low temperature (the mouth of a muffle furnace) until the paper chars and gently burns; finally, ignite completely to a temperature between 800° and 900° C. Transfer the crucible to a desiccator, cool, brush the precipitate on to the balance scoop and weigh as barium sulphate, BaSO₄.

The sulphur percentage in the steel is calculated thus:

 $\{(\text{Weight of BaSO_4}) - (\text{Weight of ``blank ''})\} \times \frac{13 \cdot 74}{5} = \text{Sulphur \% in \mathfrak{t}he steel.}$

Determination of the "Blank."

The reagents employed are always liable to contain small amounts of sulphur, so that a corrective blank determination is necessary.

This is conducted side-by-side with, and in a similar manner to, the steel determination, but without 5 g. of steel drillings, the

weight of BaSO₄ thus obtained being the blank.

Notes.

(1) It is recommended that hitherto unused glassware, including reagent bottles and measuring cylinders, be reserved exclusively for the determination of sulphur in steel by the above method.

(2) A stock of hydrochloric and nitric acids should also be similarly reserved. It is important that the stock bottles and reagent bottles be stored away from the laboratory atmosphere, in order that contamination of necks and stoppers by laboratory fumes may be avoided, unless specially designed bottles be used.

(3) The results obtained by the gravimetric aqua-regia method

must not be regarded as of greater accuracy than $\pm 0.0015\%$.

(4) When using coal-gas for heating hot-plates, contamination may result from the sulphur dioxide present in the products of combustion of the gas. This may be obviated by providing an adequate skirt in front of the plate, so that the products of combustion pass from the back into the flue of the fume chamber. A

good draught in the flue is essential in such circumstances.

(5) With steels of exceptionally low sulphur contents, such as those produced by the basic electric-furnace process, precipitation of the barium sulphate may be accelerated by the addition of a known amount of potassium sulphate solution of accurately determined strength, prior to the barium chloride addition. The amount added should be equivalent to approximately 10 mg. of barium sulphate.

THE DETERMINATION OF PHOSPHORUS IN STEEL.

The Sub-Committee has critically surveyed all existing processes

for the determination of phosphorus in iron and steel.

Practically all these methods depend, in the first instance, on a preliminary separation of the phosphorus in the form of the yellow "ammonio-phospho-molybdate," the many different processes then being concerned with the subsequent treatment of this

isolated precipitate.

As previously indicated, detailed examination showed that there existed a wide variation in the conditions laid down for complete precipitation and separation. The conditions regarding acidity of the solution, temperature of precipitation, concentration of dissolved ammonium salts, excess of precipitant, &c., were found to differ widely, and, although the initial experimental results indicated that considerable latitude was permissible in regard to these details, the conclusion reached was that it was desirable to standardise the conditions of precipitation.

All methods for subsequently dealing with the yellow precipitate, viz., its direct weighing, after drying, its conversion to lead molybdate, lead phospho-molybdate or magnesium-ammonium phosphate, and the well-known Handy volumetric finish have been

considered.

Direct weighing of the yellow precipitate was condemned in view of its uncertain composition when dried and its relatively high factor. In the lead molybdate conversion method, it was thought that here, too, the final residue would vary, so that this method was temporarily discarded. The conversion of the precipitate into magnesium-ammonium phosphate and its subsequent ignition to magnesium pyrophosphate, although its composition was recognised as being independent of the actual composition of the yellow precipitate, was ruled out since the conversion and ignition introduced other critical analytical difficulties and materially increased the multiplying factor for phosphorus.

Accordingly, it was decided to concentrate on the volumetric finish, as this provided the easiest means of checking the constancy of the composition of the yellow precipitate under standard conditions, and, after much discussion, to standardise the alkali (and acid) used in the titration by means of benzoic acid, which is obtainable in a very pure form, rather than by the more conventional method of using a standard phosphorus steel. It was indicated that in the latter case the phosphorus content of the steel would need to be determined by some other (and perhaps less accurate) method.

The influence of arsenic on the determination of phosphorus was thoroughly discussed and, at first, opinion was divided regarding the most satisfactory means of avoiding contamination of the yellow precipitate by this element. Some members of the Sub-Committee were in favour of the preliminary removal of any arsenic prior to precipitation; others considered that, provided that adequate precautions were taken, conditions could be so arranged that contamination of the precipitate was avoided, even in the presence of considerable proportions of arsenic. In consequence, it was decided to conduct experiments on relatively low- and high-phosphorus steels, in which (a) the arsenic was removed, and (b) precipitation was made in the presence of this element. In the former method, the arsenic was evolved as the tribromide after preliminary solution of the steel in perchloric acid solution.

The results obtained on the two selected steels by these processes proved disappointing, since, on the one hand, they gave no evidence of the need either of the preliminary elimination of the arsenic or of taking steps to render it innocuous during the precipitation of the phosphorus, and, on the other hand, the magnitude of the divergence of the phosphorus content from the mean value

was greater than had been anticipated.

This led to vigorous discussion, some members being definitely of the opinion that preliminary removal of any arsenic was an essential condition, others contending that this operation was a

waste of time and unnecessary.

Accordingly, in an endeavour to solve the problem, experiments were conducted on a steel of abnormally high arsenic content, containing approximately 0.25% of the element.

In this investigation, the perchloric acid and bromide methods were used, but, again, the results were disappointing, since they were not even in fair agreement, and, indeed, many members could not obtain consistent results in their own laboratories by either method. In this respect, the perchloric acid method appeared to

present the greater difficulty.

It was suggested that the variance in the results obtained by the bromide process might have been due to incomplete instructions and that in the perchloric acid method the errors might have been due to the incomplete evolution of the arsenic, mainly owing to a too rapid rate of expulsion of the hydrobromic acid when added to the boiling perchloric acid solution. (It was pointed out that the boiling point of the latter was in the region of 200° C.)

From the results obtained, it was concluded that both methods would need modification before proceeding with further experiments.

The next series of experiments was made on two steels to which arsenic had been deliberately added, and four different methods were employed, viz.:

(a) A modified perchloric acid process.

(b) A modified bromide method.(c) The zinc-reduction method.

(d) The arsenic-dissociation method (Etheridge, modified by Ridsdale).

The last method was based on the prevention of the formation of ammonium arseno-molybdate by means of a sufficiently large concentration of nitric acid. The term "arsenic dissociation" was regarded as not too satisfactory, since it implied the dissociation, or splitting-up, of a compound already formed, whereas, in reality, the nitric acid really inhibited its formation. The difficulty of formulation of a satisfactory alternative and more appropriate term was, however, appreciated.

The results obtained by the above methods showed quite definitely that the lowest average values were obtained by the arsenic-dissociation method and the highest by the zinc-reduction method, with the other two methods yielding intermediate average

values

It was generally agreed that the zinc-reduction process was unreliable and that the perchloric acid method was more suitable for alloy than for plain carbon steels. It was decided, therefore, to devote further attention to the bromide and arsenic-dissociation methods, modified in the light of the experience gained by the members of the Sub-Committee, so as to settle once and for all the question as to whether the removal of arsenic was necessary or otherwise.

Accordingly, two entirely new steels were analysed, one containing 0.004% and the other 0.20% of arsenic. The determinations were finished both gravimetrically and volumetrically, and

the results were in closer agreement than any others previously recorded. These results are shown in Table II.

Table II.—Phosphorus Determinations on Two Arsenical Steels by the Bromide and the Arsenic-Dissociation Methods.

Ana- lyst.	Steel	SG3964 (lo	w As, 0.00	Steel SG3965 (high As, 0.2%).				
	Bromide Method.		Arsenic-Dissocia- tion Method.		Bromide Method.		Arsenic-Dissocia- tion Method.	
	Volu- metric.	Gravi- metric.	Volu- metric.	Gravi- metric.	Volu- metric.	Gravi- metric.	Volu- metric.	Gravi- metric.
1	0.051	0.050	0.050		0.044	0.044	0.045	
2	0.051	0.051	0.052	0.051	0.046	0.045	0.047	0.047
3	0.050	0.049	0.049	0.049	0.042	0.044	0.045	0.044
4	0.053	0.052	0.053	0.052	0.047	0.046	0.049	0.048
5		***	0.049	0.049			0.041	0.042
6	$\left\{ egin{matrix} 0.050 \\ 0.0515 \end{smallmatrix} \right\}$	0.051	0.051	0.051	0.043	$\{ {0.045} \\ {0.046} \}$	0.045	0.043
8	0.048	0.053	$\{ \begin{array}{c} 0.048 \\ 0.049 \end{array} \}$	$\left\{egin{array}{c} 0.051 \\ 0.051 \end{array} ight\}$	0.041	0.046	$\{ \begin{array}{c} 0.044 \\ 0.044 \end{array} \}$	0.044 0.043
9	0.052	0.052	0.052		0.044	0.044	0.044	
10	0.052	0.052	0.050	0.052	0.046	0.045	0.044	0.043
11	0.050	0.051	0.048	0.049	0.045	0.045	0.044	0.043
. 12	0.052	0.053	0.052	0.051	0.043	0.045	0.042	0.044
13	0.052	0.052	0.052	0.053	0.045	0.044	0.046	0.045
14	0.048	0.051	0.051	0.050	0.042	0.043	0.044	0.046
15	0.050	0.049	0.051	0.049	$\left\{ _{0\cdot 044}^{0\cdot 042}\right\}$	0.042	0.045	0.044
17	***		0.053	0.054		***	0.047	0.048
Mean	0.051	0.051	0.051	0.051	0.044	0.044	0.045	0.044

These results clearly indicated that arsenic had much less influence on the determination of phosphorus than had been anticipated. Even so, however, the Sub-Committee decided that for a recommended referee method, the elimination of arsenic prior to precipitation of the phosphorus was desirable and, further, that the gravimetric finish was likely to yield the most consistent results. The bromide method was therefore redrafted, incorporating certain minor adjustments in consequence of experience gained. This redraft, which follows, is now put forward as a recommended method for the determination of phosphorus in carbon steels, with particular reference to cases of dispute.

Recommended Method for the Determination of Phosphorus in Carbon Steels.

Solutions Required.

Dilute Hydrochloric Acid.—Dilute 5 ml. of hydrochloric acid (sp. gr. 1·16) to 100 ml. with distilled water.

Microcosmic Salt Solution.—Dissolve 2 g. of microcosmic salt

crystals in 100 ml. of distilled water.

Molybdate Reagent.—Make a suspension of 100 g. of molybdic acid in 240 ml. of distilled water. Complete solution of the acid by the addition of 170 ml. of ammonium hydroxide (sp. gr. 0.880). Pour the solution, with repeated shaking, into 1250 ml. of nitric acid (sp. gr. 1.20) containing 2 ml. of microcosmic salt solution. Stand, and filter immediately before use.

Dilute Nitric Acid.—Dilute 2 ml. of nitric acid (sp. gr. 1.42) to

100 ml. with distilled water.

Dilute Ammonium Hydroxide.—Dilute 1 part by volume of ammonium hydroxide (sp. gr. 0.880) with 2 parts by

volume of distilled water.

Ammonium Acetate Solution.—Dilute 1 part by volume of glacial acetic acid with 2 parts by volume of distilled water and neutralise by the addition of ammonium hydroxide (sp. gr. 0.880). Just acidify by the addition of acetic acid.

Ammonium Chloride Solution.—Dissolve 25 g. of ammonium

chloride crystals in 100 ml. of distilled water.

Lead Acetate Solution.—Dissolve 4 g. of lead acetate crystals in 100 ml. of distilled water.

Procedure.

Cover 2 g. of sample in a 400-ml. conical beaker with 25 ml. of nitric acid (sp. gr. 1·42) and add cautiously 15 ml. of hydrochloric acid (sp. gr. 1·16) at such a rate that the liquid, when frothing, does not overflow. Digest until dissolved, evaporate to dryness and bake at a temperature of about 300° C. for 20 min. Cool, take up with 40 ml. of hydrochloric acid (sp. gr. 1·16) and boil until a clear solution is obtained.

Add 20 ml. of distilled water and filter through a paper-pulp pad into a 400-ml. conical beaker, washing with dilute hydrochloric acid and keeping the bulk as low as possible. Add 5 g. of ammonium bromide and, with the cover of the beaker removed, evaporate until white fumes appear and the volume is reduced to

about 4 ml.

Add 10 ml. of nitric acid (sp. gr. 1·42) and warm gently until the bromine is eliminated. Dilute with 40 ml. of cold distilled water and add ammonium hydroxide (sp. gr. 0·880) in slight excess (about 8 ml. are required). Just redissolve the precipitated ferric hydroxide by the cautious addition of 4–5 ml. of nitric acid (sp. gr. 1·42) and add 4 ml. in excess. Adjust the temperature of the solution to 80° C., add 35 ml. of filtered molybdate reagent, shake the solution until the precipitate forms and allow to stand for 20 min.

Filter the yellow precipitate on an ashless paper-pulp pad,

washing with cold dilute nitric acid until the washings are free from iron salts (usually, about six washes suffice). Transfer the funnel and filter to the neck of the original containing vessel and dissolve the precipitate through the pad by the dropwise addition of 15 ml. of dilute ammonium hydroxide, finally washing the pad two or three times with hot distilled water.

Refilter the ammoniacal extract through the same filter into a clean conical flask, washing thoroughly with hot distilled water (at least ten washes are required). Place the flask containing the filtrate on the hot-plate, together with a second flask containing 50 ml. of ammonium acetate solution and 50 ml. of ammonium chloride solution. Bring both solutions to the boil and add to the ammoniacal extract 10 ml. of hydrochloric acid (sp. gr. 1.16), followed by 8 ml. of lead acetate solution. (If a precipitate forms, clear the solution by a further addition of hydrochloric acid (sp. gr. 1.16), added dropwise.) Pour this solution into the acetatechloride solution, rinsing thoroughly with hot water. allow the precipitated lead molybdate to settle.

Filter on an ashless paper-pulp pad, washing with hot distilled water. Dry, ignite at a temperature not exceeding 650° C., cool

and weigh as lead molybdate, PbMoO₄.

Notes.

(1) The weight of lead molybdate precipitate multiplied by 0.35 equals the percentage amount of phosphorus if a 2-g. sample is taken.

(2) The method eliminates completely the influence of arsenic

in commercial steels.

(3) Results obtained by the method are accurate to $\pm 0.0015\%$ of the true phosphorus contents.

THE DETERMINATION OF LEAD IN STEEL.

In view of the introduction of lead into steel during recent years for the purpose of improving its machinability, the Sub-Committee was requested to formulate a reliable process for its determination. Three existing methods were considered, in which the main differences were in the means adopted for the separation of the lead, viz. (a) the sulphide process, (b) the ether-separation and (c) the sulphate method.

It was decided that the sulphide method was unsatisfactory, since both the acid concentration and the temperature are too critical and the precipitation is influenced by the presence of other dissolved salts. Although it was acknowledged that the ether method gives excellent results when operated by a chemist well experienced in the process, it was felt that it could not be generally

recommended.

Attention was concentrated, therefore, on the sulphate method

of separation, and, at first, in view of the well-known fact that lead tends to segregate to a marked extent in steel, it was decided to employ synthetic solutions, i.e., a mild steel was dissolved in acid and a definite amount of standard lead acetate or lead nitrate solution was added.

Fair agreement was obtained, but the results were not considered good enough, so that further refinements were introduced.

The method finally approved of is described below.

Recommended Method for the Determination of Lead in Steel. Solutions Required.

Ammonium Acetate Solution.—Dilute 1 volume of glacial acetic acid with 2 volumes of distilled water and neutralise with ammonium hydroxide (sp. gr. 0.880); just acidify with the acetic acid solution and finally dilute with an equal volume of water.

Ammonium Molybdate.—Dissolve 5 g. of ammonium molybdate crystals in 100 ml. of distilled water and make ammoniacal with a few drops of ammonium hydroxide

(sp. gr. 0.880). Filter the solution before use. 5% Sulphuric Acid.—Add 5 ml. of sulphuric acid (sp. gr. 1.84) to 85 ml. of cold distilled water; add 10 ml. of methylated spirit and dilute to 100 ml.

Procedure.

Cover 10 g. of sample in a covered 600-ml. squat-type beaker with 80 ml. of distilled water and add cautiously 20 ml. of sulphuric acid (sp. gr. 1.84). Digest until dissolved and fume for 10 min. Cool.

Add, cautiously, 200 ml. of hot water and boil to ensure complete solution of iron salts. Cool, add 50 ml. of alcohol (industrial methylated spirit) and stand for 2 hr.

Filter the lead sulphate on a paper-pulp pad, washing with 5%

sulphuric acid containing 10% of alcohol.

Dissolve the lead sulphate through the pad by the addition of at least three portions of hot ammonium acetate solution of 10 ml. each (allowing each to drain before adding the next), followed by several washes with hot water. Make the resulting solution alkaline by the addition of 5 ml. of ammonium hydroxide (sp. gr. 0.880). Boil, and precipitate lead molybdate by the dropwise addition of 20 ml. of 5% ammonium molybdate solution.

Filter on an ashless paper-pulp pad, washing with hot distilled water. Dry, ignite at a temperature not exceeding 650° C., cool and

weigh as PbMoO₄, containing 56.42% of lead.

Using the above method, analyses were repeated on synthetic solutions and also on a remarkably uniform leaded steel provided by a member of the Sub-Committee. The results are shown in Table III.

Table III.—Lead Determinations on Synthetic Solutions and a Leaded Steel.

Analyst.	Synthetic S	olutions; Lead			,	
	0.05%.	0.15%.	0.30%.	Leaded Steel.		
1	0.048	0.149	0.303	0.28	0.28	
2	0.045	0.147	0.296	0.29	0.29	
3	0.047	0.148	0.299	0.28	0.28	0.28
5	0.049	0.147	0.298	0.30		
6	0.048	0.144	0.306	0.28	0.28	0.28
7	***	***	***	0.28	0.28	
8	0.046	0.148	0.296	0.27		
9	0.050	0.146	0.282	0.28	0.28	0.28
10	• • •	***	***	0.29		
11	0.048	0.148	0.299	0.28	0.28	
12	0.045	0.148	0.296	0.28	0.28	0.28
13	0.049	0.148	0.297	0.27		
14	0.043	0.147	0.297	0.28	0.28	0.27
15	0.050	0.149	0.297	0.28	0.29	
16	0.045	0.150	0.291	0.28	0.26	

Notes.

(1) This method is not recommended for high-chromium steels.

(2) It is unnecessary to report lead figures beyond the second

decimal place.

(3) It is recognised that in leaded steels segregation of lead occurs to an extent greater than the segregation of ordinary elements in non-leaded steels. It is therefore desirable that the analysis be carried out on a uniform sample, and for this purpose it is recommended that the section be not greater than 2 in. in dia. and that millings for the referee sample be taken across the entire cross-section.

CORRESPONDENCE.

Mr. T. Henry Turner (London and North Eastern Railway Co., Doncaster) wrote: It is hoped that the Standard Methods of Analysis Sub-Committee will continue their work. There is a need for standardised methods of sampling and chemical analysis of carbon and alloy steels, including all normal alloying elements and oxygen, hydrogen and nitrogen.

Our laboratories have much appreciated the work of Mr. N. D. Ridsdale in endeavouring to produce standards for use in the laboratory, and each time we co-operate in such a standardisation we gain a better insight into the normal variations to be expected

when using existing methods of analysis.

We have also found the British Cast Iron Research Association's booklet entitled "The Sampling and Chemical Analysis of Cast

Ferrous Metals" of value.

When occasion permits the production of a similar booklet on the analysis of steels, this should also include reference to spectrographic methods. It will then be of great value to many laboratories. The Standard Methods of Analysis Sub-Committee would seem to be the body which should undertake the production of such a booklet, and it may therefore be worth suggesting that, if the work cannot be carried out at the moment owing to shortage of staff, it should be considered as a matter worth listing on the research programme to be undertaken when suitable staff is at liberty.

Mr. E. Taylor-Austin (The Darwen and Mostyn Iron Co., Ltd., Mostyn, Flintshire) wrote: I have read the Sub-Committee's Report with very great interest, but, as one who has carried out considerable experimental work on methods for the determination of sulphur, including several modifications of the combustion process, I feel that I must emphatically disagree with the statement that this latter process is not truly stoichiometric and depends for its standardisation on steel samples of known sulphur content. The standardisation of the N/200 sodium hydroxide for use with neutral silver nitrate absorbent is not an easy matter, owing to the difficulty of obtaining a satisfactory end-point to the titration of so dilute a solution. I have, however, shown that, if the sodium hydroxide is very carefully prepared and standardised at a dilution of N/20 against oxalic acid, being subsequently diluted exactly ten times, the theoretical factor, as derived from the equation $SO_2 + 2AgNO_3 + H_2O = Ag_2SO_3 + 2HNO_3$, can be obtained (1 ml. of N/200 NaOH = 0.00008 g. of sulphur.

In general practice it is more expedient to prepare approximately N/200 sodium hydroxide solution and obtain a factor by carrying out a determination on a steel of known sulphur content, but the

fact remains that a theoretical basis can be established for the

combustion sulphur process.

The pitfalls and possibilities of error with which the aqua regia gravimetric method abounds are very numerous and too wellknown to require mention. The Sub-Committee have undoubtedly tended to minimise the apparent effects of such errors as those due to adsorption of barium chloride, co-precipitation of ferrous sulphate, &c., by rigid standardisation of the conditions of precipitation, but I still feel that the combustion process, properly handled, is capable of yielding results at least as accurate as those produced by the gravimetric method in but a fraction of the time and with but a fraction of the labour.

Regarding the determination of phosphorus, I would like to draw the attention of the Sub-Committee to a series of experiments carried out by me and reported some time ago. Since the lead molybdate finish, incorporated in the standard procedure, amounts virtually to a determination of molybdenum on the yellow precipitate, the work referred to above has considerable bearing on the subject. I have shown that if the molybdate is precipitated from acetic acid solution, instead of the usual hydrochloric acid buffered with ammonium acetate, a wide range of acid concentration may be employed and a granular precipitate which is easy to filter and wash is obtained. Washing must be carried out with hot 2% acetic acid solution. If the precipitation is carried out under these conditions, the procedure is considerably simplified and only one flask or beaker is required instead of two. It is, of course, still necessary to add ammonium chloride to inhibit the precipitation of lead phosphate, but this can readily be done before the addition of the lead acetate solution. I have successfully applied the above-mentioned process to the determination of phosphorus in amounts ranging from 0.01% to 1.5%.2

Mr. L. Perrett (The Briton Ferry Steel Company, Ltd., Briton Ferry, Neath, Glam.) wrote: The Sub-Committee have undoubtedly come forward with excellent material in the Report under discussion, and the amount of work that this must have entailed can be readily appreciated when consideration is given to the varying methods that they had to examine. The need for standard methods has long been felt by all interested parties.

While agreeing that the Sub-Committee have chosen rightly in first of all devoting their energies to the establishment of standard "referee" methods for the determination of phosphorus and sulphur, I hope that they will have an opportunity, at an early date, of investigating and publishing standard "routine" methods for these two elements. I feel that, under present-day conditions,

Analyst, 1937, vol. 62, pp. 107–117.
 E. Taylor-Austin, "The Sampling and Chemical Analysis of Cast Ferrous Metals," p. 40. Birmingham, 1941: British Cast Iron Research Association.

it is more necessary than ever that such methods should be capable

of presenting accurate returns as quickly as possible.

The aqua regia method for sulphur in use at the laboratories of The Briton Ferry Steel Co. follows closely, in some respects, the one given in the Report, being based on that given by Gregory and Stevenson in "Chemical Analysis of Metals and Alloys," and I find it quite satisfactory. I was surprised to find, in the recommended method, that the barium chloride solution was added without boiling, and apparently at once. My experience is that a drop-wise addition of this reagent to a just boiling solution is better, as the barium sulphate precipitated is then granular. This is followed by boiling for two minutes before overnight settling.

Comparing our evolution method with the gravimetric, no great difficulty, over the usual commercial range of sulphur, has been experienced. For the special checking of solutions I use steels that have been annealed in nitrogen as advocated by Rooney, and think it would be of interest if the Sub-Committee would give their views on the possibility of obtaining the full sulphur content by evolution methods after this treatment. As stated by Dr. Gregory, in presenting the Report at the Meeting, the choice of solvent for the hydrogen sulphide is very important, also the

release solution used.

In the determination of phosphorus I have never found it necessary to separate arsenic, using our present method. Tests carried out lead me to believe that it would be a waste of time, although I believe Dr. Gregory to be right when he says that pig iron is definitely affected. Many years ago for the finish direct weighing of the yellow precipitate was used, first by brushing off the paper and later by weighing on counterpoised papers; both ways were objectionable for obvious reasons, and the conventional volumetric finish is now used. Standard steels are not used to ascertain the phosphorus value of the alkali and acid solutions, while benzoic acid has been recognised as a suitable medium for standardisation, and can be obtained in a pure form; I think that to expel any hygroscopic water, before use, it should either be fused just above its melting point, with the possibility of decomposition, or kept drying in a desiccator over sulphuric acid for a long period—either method has its disadvantages. Oxalic acid can also be obtained in a very pure form and is stable, and I have used reputable A.R. crystals for over twenty years for standardisation with every success.

Since the publication of the recommended method I have been able to carry out a certain amount of work with it and have found it quite satisfactory in operation. The one operation where there appears to be a possibility of error is in the incomplete washing

of the pulp after refiltering the ammoniacal extract.

Although no steel with 0.25% of arsenic was available I have compared our method with this one on 0.025-0.035% arsenic steels

¹ Journal of The Iron and Steel Institute, 1921, No. I., p. 343.

and obtained results which compare well, being accurate to within $\pm~0.002\%$ of each other. Steels of high and low phosphorus content were examined.

The next step taken was to make determinations, using the same sample, first by the full gravimetric method as given and secondly by carrying others as far as the precipitation of the yellow precipitate by the recommended method and finishing volumetrically in the usual manner. The results obtained in both instances were within $\pm~0.001\%$ of each other. At the same time results obtained by the routine method were also within $\pm~0.002\%$ of the foregoing.

Until recently I had not been called upon to determine lead in lead-bearing steels, but had frequently been asked to determine the weight of lead coating on terne plates, and had used a method for this work which was found satisfactory for lead-bearing steels

when the necessity arose.

In the early days experience with sulphide separations proved them to be quite unreliable for routine work and I eventually fell back on the sulphate method. Hydrochloric acid (sp. gr. 1·16) is used as the solvent and sulphuric acid is added when solution is complete, afterwards evaporating to fumes. After fuming, the salts are taken up in cold water, and, after standing, the lead sulphate is filtered off through paper-pulp, washing the latter well with dilute sulphuric acid. The paper-pulp with the lead sulphate is transferred to the original beaker, 30 ml. of ammonium acetate solution are added and the lot is heated just short of boiling for ten minutes. The paper-pulp is filtered off through another small pad and washed well with hot distilled water; the filtrate is heated to boiling and immediately titrated with standard ammonium molybdate solution, using a 0.50% solution of tannic acid as external indicator, the end-point being a change to yellow. This volumetric finish compares well with a weighing of lead molybdate and at the same time obviates two dangers, which I think might affect gravimetric results. The first is that it is doubtful whether a single precipitation of lead molybdate does give a pure precipitate, and I feel that a reprecipitation should be made after ignition, and reignited; the second is the danger of overheating during ignition, which is done away with.

At the moment experiments are being carried out using potassium chromate for the titration of the lead solution, with silver nitrate as external indicator, as I believe that this will give a somewhat sharper end-point, but sufficient work has not been carried out

yet to make any positive statement.

Since the publication of the Report I have had little opportunity of putting the recommended method for lead into operation, but one initial advantage over the method given above seems obvious, namely, that solution in sulphuric acid should speed up the determination considerably.

Mr. A. Allison (Messrs. J. J. Habershon & Sons, Ltd., Rotherham) wrote: Whilst admitting that each chemist considers his methods to be the best, the Sub-Committee's recommended methods of analysis for sulphur and phosphorus, in my opinion, are capable of still further improvement. In the sulphur method no mention is made of the imperative necessity of rinsing out beakers with distilled water before use, nor, more particularly, before filtering off silica, of washing the filter and reception beaker thoroughly. Since many tap waters contain calcium sulphate this point should have been stated.

For dissolving the drillings, the orthodox practice is to use a small quantity of potassium chlorate and cover the drillings with strong nitric acid, adding hydrochloric acid cautiously until the appropriate quantity can be added. This is much neater than adding mixed acids and more certain to retain the sulphur in

solution.

Has the Sub-Committee tried a free-cutting steel with mixed acid addition?

Curiously enough, the Sub-Committee recommend adding strong nitric acid first for dissolving the steel in the phosphorus method; phosphorus is much less liable to be lost than sulphur.

Actually, a cast iron containing 0.5% of phosphorus was dissolved in cold hydrochloric acid, and the whole of the phosphorus

was recovered from the solution.

In sulphur estimations it has always been understood that nitric acid interferes with the precipitation of barium sulphate, and it is doubted whether baking and subsequent evaporation remove it completely. At all events a second evaporation seems to give a sharper precipitation, using, of course, acid quantities rather smaller than those specified. It is strange that the Sub-Committee make no reference to the zinc reduction method before precipitating the barium sulphate, which is said to improve matters.¹

I consider that boiling after adding barium chloride improves matters, and if by any chance the solution dries on the side of the beaker, producing flakes of ferric hydrate on the barium sulphate precipitate, I have found experimentally that "spotting" with strong hydrochloric acid purifies the precipitate without loss.

With regard to the phosphorus method, I consider that nitric acid (sp. gr. 1·20) is a satisfactory solvent for the purpose (adding hydrochloric acid only if necessary), and I would prefer the volumetric finish. For many years I have used as standard a solution of a definite phosphate salt, from which the yellow precipitate is formed in the usual way, for standardising the soda solution. What is more natural for estimating phosphorus than to use a definite compound of phosphoric acid?

¹ "Sampling and Analysis of Carbon and Alloy Steels," p. 107. New York, 1938: United States Steel Corporation. Also C. Meinecke, Zeitschrift für analytische Chemie, 1899, vol. 38, p. 209.

The method recommended is stated not to be more reliable than $\pm~0.0015\%$. That means that duplicate results of, say, 0.035% and 0.038% might be found. I would expect better duplicates than that, and I think that the methods might be examined further.

SUB-COMMITTEE'S REPLY.

The Sub-Committee, in reply, wish to express their appreciation of the interest taken in the Report.

Mr. Turner's comments are particularly welcome and his suggestion that the recommended methods should be published in booklet

form is actually under consideration.

Mr. Taylor-Austin's remarks are of interest, but the Members of the Sub-Committee emphatically disagree with his conclusions. In the first place, Mr. Taylor-Austin claims that the combustion sulphur process is stoichiometric, but puts forward no evidence beyond some facts about the standardisation of the sodium hydroxide solution. Whilst even his suggested method of standardisation is not without error, owing to dilution, the Sub-Committee are somewhat surprised that they have not been credited with paying due attention to standardisation and cannot agree that the use of a correctly standardised solution is, in itself, proof of the stoichiometric nature of the combustion process. From a careful study of all the results obtained by the combustion method, as normally practised in Great Britain, and after taking precautions to ensure as far as possible that loss of evolved sulphur dioxide and sulphur trioxide did not occur as the result of absorption or adsorption by the combustion boat or tube, or fume-removing pads, the conclusion was reached that the process was not strictly stoichiometric, a conclusion amply confirmed in the published literature on the subject.

The Sub-Committee agree that the speed and simplicity of the combustion process are advantageous, and the process has actually been under consideration for some time by the Sub-Committee as a possible recommended method for the determination of sulphur in highly alloyed steels, but the evolution of the most reliable method, not necessarily the simplest or most rapid, and independent of any

other process, must remain the first consideration.

In regard to the determination of phosphorus, the Sub-Committee are fully conversant with Mr. Taylor-Austin's paper in the Analyst and his recommended procedure on p. 40 of the British Cast Iron Research Association handbook. But has Mr. Taylor-Austin overlooked the fact that in his gravimetric procedure in making the solution acid with acetic he thereby generates ammonium acetate in that solution? To the Sub-Committee, there appears to be little difference between a solution of ammonium chloride and acetic acid, and a solution of ammonium acetate and hydrochloric acid when

the relevant radicles are present in similar amounts, and it may also be pointed out that the recommended method does not employ a buffered solution, but simply requires the addition of hydrochloric acid, ammonium acetate and ammonium chloride to realise the most suitable concentration of salts in the solution. Assuming that Mr. Taylor-Austin uses a vehicle to add the ammonium chloride which he admits is necessary, the Sub-Committee, quite frankly, cannot understand why this point has been raised.

The Sub-Committee welcome Mr. Perrett's comments and thank him for his complimentary remarks. But, whilst fully appreciating his views on the need for establishing quick and reasonably accurate methods for sulphur and phosphorus, it is necessary to stress the point that the Sub-Committee was formed with the primary object of devising recommended methods for arbitration rather than for

routine purposes.

Mr. Perrett apparently favours the drop-wise addition of barium chloride in the determination of sulphur as barium sulphate, but, whilst no harm can possibly result from this procedure, which, indeed, has much to recommend it, the Sub-Committee consider that it is not necessary when the sulphur content is below 0.08%.

If the solution, which is rich in ferric chloride, is boiled, hydrolysis of some small amount of ferric chloride may occur, with the result that the final residue is contaminated with oxide of iron.

Mr. Perrett's observations on the phosphorus methods are interesting, but the Sub-Committee would draw his attention to p. 289 r of the Report, where it is stated quite definitely that the influence of arsenic was much less than had been anticipated. The Sub-Committee are gratified to learn that Mr. Perrett has obtained such excellent agreement by the recommended method, employing both the gravimetric and the volumetric finish. The results given in Table II. clearly show that the latter yields good results, but it is considered that the gravimetric process is likely to yield reproducible values of a somewhat higher order of accuracy.

Oxalic acid is, of course, a useful reagent for the standardisation of alkali solutions, but the Sub-Committee are of the opinion that, for particularly accurate work, benzoic acid is preferable, since it contains no water of crystallisation and is obtainable in a very high state of purity. Incidentally, it has not been found necessary to

fuse the benzoic acid before use.

In regard to the determination of lead, Mr. Perrett's method is of interest, although low results would be expected, since no alcohol is used to reduce the solubility of the lead sulphate to an absolute minimum.

The Sub-Committee are conversant with the volumetric ammonium-molybdate method for the determination of lead, using tannin as external indicator, and this is quite satisfactory in the analysis of many non-ferrous alloys, but the Members are definitely of the opinion that, for the relatively small proportions present in

leaded steels, the gravimetric finish is better, and no necessity for reprecipitation of the lead molybdate has been found.

The results in Table III. speak for themselves, and it is felt that Mr. Perrett will be perfectly satisfied when he has had the oppor-

tunity of trying out the method.

Mr. Allison apparently expects closer accuracy than \pm 0·0015% for either sulphur or phosphorus, and it may be stated at once that the Sub-Committee are of the opinion that greater accuracy is possible with duplicates analysed in the same laboratory by the recommended methods, but that closer agreement cannot be expected between the results of chemists working in different laboratories and under different conditions. In this regard, Mr. Allison will no doubt be interested in the following extract from the "Metals Handbook," 1939 edition, p. 690 (American Society for Metals): "Determination of Sulphur.—Sulphur, like phosphorus, is reported to the third decimal place, though if results on the same sample from different laboratories check within 0·005% for plain steel, or within 0·010% on some alloy steels, the work is considered satisfactory, except where the highest accuracy is desired. . . ."

Even if Mr. Allison's criticism that ± 0.0015% means that duplicate results of 0.035 and 0.038% might be obtained is accepted, it must be stressed that a truly duplicate determination involves duplicate blank determinations. It is not strictly permissible to use a mean blank unless a mean determination is also accepted.

To obtain the deviation between two pairs of such determinations the higher-determination figure should be combined with the lower blank, and the lower-determination figure with the higher blank. The deviation should not, it is contended, under these conditions, exceed ± 0.0015 , *i.e.*, 0.003%. A variation of 0.003% when using

the mean blank is greater than is permissible.

The Sub-Committee are surprised that Mr. Allison thought fit to mention the rinsing-out of beakers with distilled water before use, since this is an elementary laboratory precaution in the determination not only of sulphur but of any other element, and surely no one would dream of making filter-pulp and pads with tap-water. However, where these precautions are not usual, the first two injunctions given on p. 286 P are sufficiently emphatic to indicate the need for supercleanliness.

There is no reason why potassium chlorate should not be used instead of potassium nitrate if one is content with a still more obnoxious atmosphere within (or without) the fume-chamber. Most Members of the Sub-Committee have used the recommended method for free-cutting steels and have obtained excellent results, comparable with those obtained by the combustion and even the

evolution processes.

In connection with the solution of the steel, the Sub-Committee wonder, in view of the diverse procedures originally submitted, what really constitutes "orthodox practice." Mr. Allison can rest

assured that both methods of adding the acids have been used by most Members at various times, and there is not much evidence to support either technique against the other. The mixed-acid method is, however, a question of convenience, as, when using 5 g. of steel for the sulphur determination, the contents of the containing vessel are more likely to froth over than when 2 g. only are used, as in the determination of phosphorus. Again, by using mixed acids, uniform treatment of all samples is ensured, and, moreover, the Sub-Committee feel that there is less danger of accidental contamination of isolated members of batch determinations. Incidentally, high-sulphur steels of the free-cutting type are analysed regularly by the

mixed-acid method with complete confidence. One of the main objects of the Sub-Committee's standardisation has been to make the methods as simple as possible consistent with accuracy, and such procedures as double evaporation, zinc reduction, boiling the solution after addition of the barium chloride, &c., have all been considered and investigated. The double evaporation is unnecessary, and the addition of potassium sulphate to low-sulphur steels fulfils the function of the zinc reduction which, Mr. Allison states, somewhat vaguely, is said to improve matters. Members who have tried it have not found any real improvement over the method in which precipitation is made from ferric solutions, and the Sub-Committee surely cannot recommend a procedure which, to quote Mr. Allison's own words, tends to contaminate the barium sulphate with ferric hydroxide which "is removed without loss" by spotting with strong hydrochloric acid. After careful consideration of the results of much experimental work, the Sub-Committee are definitely of the opinion that the acid concentration must be carefully controlled, but Mr. Allison's procedure will result in acid concentrations that will vary from one assay to another.

Regarding the phosphorus method, Mr. Allison will find in the Report many references to the Sub-Committee's general preference for the volumetric method for routine work, but in view of their researches the Sub-Committee were forced to conclude that the gravimetric method tends to greater consistency and must be

recommended in cases of dispute.

Mr. Allison's experience in dissolving a 0.5% phosphorus cast iron in hydrochloric acid without loss of any phosphorus as PH₃ is interesting, but surely he is not suggesting a non-oxidising acid for opening-out in the determination of phosphorus in steel.

This report was presented for discussion at a Joint Meeting, organised by The Iron and Steel Institute in conjunction with the Sheffield Society of Engineers and Metallurgists, the Sheffield Metallurgical Association and the South Yorkshire Section of the Institute of Chemistry, held in the Assembly Room, Royal Victoria Station Hotel, Sheffield, on Wednesday, 24th June, 1942, at 7 P.M., under the Chairmanship of Dr. W. H. Hatfield, F.R.S. (Vice-President of The Iron and Steel Institute; President of the Sheffield Society of Engineers and Metallurgists). The discussion will be recorded in the No. II. volume of the Journal of The Iron and Steel Institute for 1942.

SECOND REPORT ON REFRACTORY MATERIALS.

BY A JOINT COMMITTEE OF THE IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL AND THE BRITISH REFRACTORIES RESEARCH ASSOCIATION.

This Report is published as Special Report No. 28; it was presented at the Annual General Meeting of The Iron and Steel Institute in London on May 7, 1942. Papers Nos. 2 and 3 of Section B also formed part of the basis of discussion when "Open-Hearth Furnace Refractories" were debated at a Joint Meeting of the Sheffield Society of Engineers and Metallurgists, the Sheffield Metallurgical Association, the Refractories Research Association of Great Britain and The Iron and Steel Institute, held at Sheffield on May 19, 1942 (see p. 307 p),

SUMMARY.

The Report, comprising 168 pages, is divided into four main Sections. Section A, which consists of a Foreword explaining the nature of the research work which has been carried out since the publication of the First Report in 1939, gives lists of the members of the Joint Refractories Research Committee, Panels and their Sub-Committees of the Iron and Steel Industrial Research Council and the British Refractories Research Association. Sections B and C deal with steelworks and blast-furnace refractories, respectively. Section D gives a summary of other privately published work of the British Refractories Research Association which is of interest to the iron and steel industry.

Section B begins with a review of the work of the Open-Hearth Refractories Joint Panel since 1939 (Paper No. 1). Three phases of research have been proceeding concurrently: (1) Investigations on silica bricks, which have developed from a general survey to an intensive study of one roof; (2) work on basic refractories, which has ranged from studies of the constitution of stabilised dolomite and chrome ores to the preparation of test sheets for the service testing of basic refractories in the open-hearth furnace; and (3)

work on casting-pit refractories.

Paper No. 2 on the reactions between dolomite and the various minerals is in four parts. In Part I. J. R. Rait and A. T. Green report on tests of moulded mixtures, in various proportions, of dolomite with flint, steatite, bentonite, china clay, olivine, serpentine, open-hearth slag, alumina, ferric oxide, zircon, baddeleyite, zirconia, rutile, chromite and chromium oxide fired at about 1500° C. Qualitative tests for the presence of free lime in the fired clinkers were made. With increasing additions of silica or siliceous minerals the evidence indicated the increasing combination of lime to form,

first, tricalcium silicate and, with larger silica contents, dicalcium silicate. In Part II. J. R. Rait and H. J. Goldschmidt give an account of their X-ray investigation of fired dolomite-steatite mixtures containing initially from 0 to 15% of steatite, and of two commercial dolomite bricks. The proportion of free lime present in the fired mixes decreased to nil as the initial steatite content increased to 8-10%, at which composition there was the maximum production of 3CaO.SiO₂. Further X-ray work by the same two investigators is reported in Part III. The object of this investigation was to obtain confirmation of the mineral constitutions as calculated from the data relating to the clinkers discussed in Part I.. assuming that the reactions in the clinkers had proceeded to equilibrium. The results of the X-ray analysis were in close agreement with the calculated mineralogical composition. Part IV., also by J. R. Rait and H. J. Goldschmidt, is an account of an X-ray analysis of fired mixes of dolomite with various proportions of zirconium minerals. From the photographs obtained, conclusions regarding the constitutions were drawn which substantiate those based previously on determinations of uncombined lime, steam hydration indices and on a consideration of the available thermal equilibrium data. This Section concludes with a brief note (Paper No. 3), by W. J. Rees, on the properties of briquettes made of a mixture of ground dolomite 95%, ball clay 2.5% and mill scale 2.5%, tempered with water containing a little sulphite lye; these briquettes were burned at 1500° C., crushed and made into test-pieces. The refractory properties were very satisfactory, and it appeared likely that bricks made from this partially stabilised dolomite mixture would have a better slag and spalling resistance than bricks made from a dolomite fully stabilised by silica additions.

Section C, on blast-furnace refractories, consists of two papers. In Paper No. 4 G. R. Rigby and A. T. Green discuss how the conditions prevailing in a blast-furnace influence the life of the refractory lining. The factors governing burden distribution are shown to have an important influence on the temperatures prevailing at the lining face. A summary of laboratory investigations on carbonmonoxide attack, alkali attack and the action of blast-furnace slags on refractory materials, and a discussion of the influence of water-cooling in the stack, the effect of insulation, and the blowing-in of the furnace, are also included in this paper. In Paper No. 5 G. R. Rigby, H. Booth and A. T. Green describe how they attempted to assess the rate at which a blast-furnace lining wears back; this was done by inserting thermocouples in five planes in the stack and bosh and taking continuous records of the temperatures. These records were correlated with variations in the flow of the blast through the stack due to burden changes. In an Appendix to this paper the effect of segregation of the burden

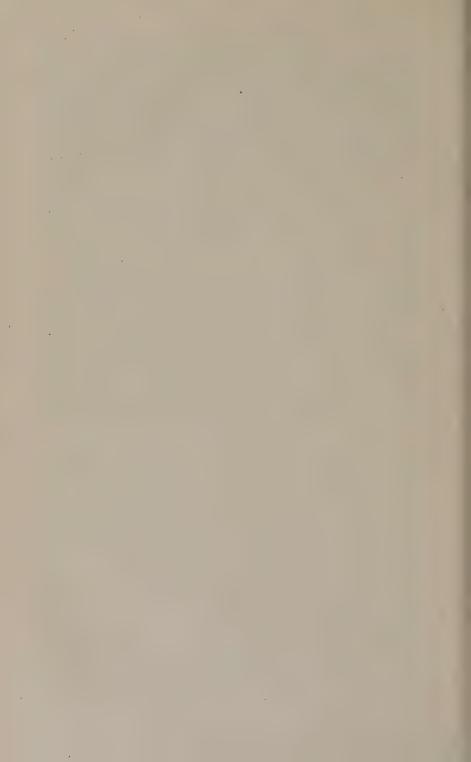
on the life of the lining is treated in a general manner.

The summary of other published work of the British Refrac-

tories Research Association (Paper No. 6), which is given in Section D, deals with: Dolomite products; the actions of slags, vapours and gases on refractories; the manufacture of carbon blocks for blast-furnace hearths by dry-press or tamping methods from foundry coke and gasworks pitch; the properties of refractory jointing cements; and high-temperature insulating refractories.

(Abstracts of the foregoing papers will be found in Section II. of this volume, pp. 209 A-213 A).

X



DISCUSSION ON OPEN-HEARTH FURNACE REFRACTORIES.

A Joint Meeting, organised by The Iron and Steel Institute in conjunction with the Sheffield Society of Engineers and Metallurgists, the Sheffield Metallurgical Association and the Refractories Association of Great Britain, was held in the Assembly Room, Royal Victoria Station Hotel, Sheffield, on Tuesday, 19th May, 1942, at 5.30 p.m.; Dr. W. H. Hatfield, F.R.S. (Vice-President of The Iron and Steel Institute; President of the Sheffield Society of Engineers and Metallurgists), took the Chair.

The subject for discussion was "Open-Hearth Furnace Refractories," and was divided into two parts: (a) Dolomite Bricks, and (b) Open-Hearth Roofs, including Temperature Control. The discussions were based on recent publications of The Iron and Steel Institute and were introduced by speakers as indicated below:

(a) Dolomite Bricks.

(1) The Stabilisation of Dolomite—Laboratory Studies, introduced by Dr. J. R. RAIT. (Basis: Section B, Paper No. 2 of the "Second Report on Refractory Materials." (The Iron and Steel Institute, 1942, Special Report No. 28). For abstracts of the papers in this Report, see pp. 209 A-213 A of this Journal).

(2) Dolomite Bricks for Use in Steelworks, introduced by Dr. T. Swinden. (Basis: "Dolomite Bricks for Use in Steelworks," by T. Swinden, D.Met., and J. H. Chesters, Ph.D., B.Sc. (Journal of The Iron and Steel Institute, 1941, No. II.,

pp. 105 P-118 P)).

(3) Semi-Stable Dolomite Bricks, introduced by Dr. W. J. REES. (Basis: Section B, Paper No. 3 of the "Second Report on Refractory Materials").

(b) Open-Hearth Roofs, including Temperature Control.

Introduced by Dr. T. SWINDEN.

(4) Low-Temperature Roof Pyrometry.—Thermocouple Control in Heating up Furnaces, introduced by Mr. T. R. Lynam. (Basis: "A Co-operative Investigation of the Factors influencing the Durability of the Roofs of Basic Open-Hearth Furnaces." (Journal of The Iron and Steel Institute, 1941, No. II., pp. 203 p-262 p)).

(5) High-Temperature Roof Pyrometry.—The Use of Roof Pyrometers in Maturing the Roof and Increasing its Life, introduced by Mr. A. E. Dodd. (Basis: The above-mentioned

paper on Basic Open-Hearth Roofs).

(6) The Microstructure of Used Roof Bricks, introduced by

Mr. W. Hughll. (Basis: Section VI. of the above-mentioned paper on Basic Open-Hearth Roofs).

The Chairman (Dr. W. H. Hatfield, F.R.S. (The Brown-Firth Research Laboratories, Sheffield)), in opening the proceedings, said: Dolomite bricks and furnace roofs are clearly of the utmost importance. As a Member of the Iron and Steel Industrial Research Council (British Iron and Steel Federation), representing the whole of the industry, I can tell you that we are greatly interested in encouraging research on refractories. It is now probably four or five years since Dr. Swinden was asked to be Chairman of the Refractories Committee, and the Research Council, on its part, makes a large grant annually to this Committee; we do that to show a real desire on our part to assist in the encouragement of fundamental work on this subject. I am sure you will all agree that we are now arriving at a stage when we are getting a very adequate return for the interest shown by our industry and by the British Refractories Research Association, who have collaborated with us so well.

I will ask Dr. Swinden, as Chairman of the Joint Refractories Research Committee of the Iron and Steel Industrial Research Council and the British Refractories Research Association, to make a

few opening remarks.

Dr. T. Swinden (Member of Council; the United Steel Companies, Ltd., Stocksbridge, near Sheffield): This meeting is to receive papers which are essentially the product of the Joint Refractories Research Committee of the Iron and Steel Industrial Research Council and the British Refractories Research Association. The papers chosen for discussion have been selected partly from the Second Report on Refractory Materials which has just been issued. The paper on basic open-hearth roofs was presented rather earlier, and unfortunately could not be incorporated in that Report, but it is a product of the Open-Hearth Refractories Joint Panel. The small paper by Dr. Chesters and myself, on dolomite bricks, while written independently of the Committee, bears so very closely on the other work referred to in the Report, that it can usefully be taken at the same time.

It has not been easy to decide a method of presenting this Report and these papers, but it has been thought wise just to select two subjects, namely, Dolomite Bricks and Open-Hearth Roofs, and so you will in due course have presented to you the paper by Dr. J. R. Rait on the stabilisation of dolomite by way of laboratory studies; the paper on dolomite brick manufacture and use, by Dr. Chesters and myself; that on semi-stable dolomite bricks by Dr. Rees; and then the paper on the factors influencing the durability of the roofs of basic open-hearth furnaces, dealt with under three headings: Low-temperature roof pyrometry, high-temperature roof pyrometry,

and the microstructure of used roof bricks. It is, I think, a particularly happy thing that we have here representatives of both the manufacturing industry and the using industry, and something very useful should emerge from the discussion.

DOLOMITE BRICKS.

- Dr. J. R. Rait (Messrs. Wm. Jessop & Sons, Ltd., Sheffield) then introduced the subject of "The Stabilisation of Dolomite—Laboratory Studies" (Basis: Section B, Paper No. 2 of the "Second Report on Refractory Materials," The Iron and Steel Institute, 1942, Special Report No. 28).
- Dr. T. SWINDEN next introduced the paper by himself and Dr. J. H. Chesters on "Dolomite Bricks for Use in Steelworks" (Journal of The Iron and Steel Institute, 1941, No. II., pp. 105 P-118 P). In doing so, he said: The paper is now some ten months old, and was written with the object of showing that the manufacture of stable dolomite bricks has been established along scientific lines and under proper control—in other words, to give confidence in the wider use of these bricks.

The fundamental features of stabilised dolomite clinker are established, and attention is drawn to the value of X-ray work in arriving at this understanding. Semi-stabilised dolomite bricks, which have their own field of usefulness, are referred to, and are being dealt with in more detail by Dr. Rees.

Reference is also made to other types of bricks in which dolomite is an essential constituent, some of which show distinct promise.

Nothing in our later experience leads to modification of any of the statements made in the paper, and it is with pleasure that one records that the various manufacturers of these bricks are now working in the closest co-operation, dealing with all the various points in manufacturing technique and research in order to provide complete confidence in their future use. It is stressed that dolomite bricks should not be regarded as a wartime substitute material, but as providing the basis for a thoroughly worth-while peacetime industry in this country.

Dr. W. J. Rees (Department of Refractory Materials, The University, Sheffield) then introduced his paper on "Semi-Stable Dolomite Bricks" (Basis: Section B, Paper No. 3 of the "Second Report on Refractory Materials"). He said: The purpose of this short note, which I presented some time ago, was to indicate the commercial possibility of the production of semi-stabilised dolomite bricks. Some twelve or fifteen years ago I was concerned with carrying out some commercial-scale experiments on the production of a dolomite clinker more stable than the ordinary basic, and one which would stand transport without hydration and could be kept

in stock for longer periods than ordinary basic. These experiments were made by adding small proportions of clay and mill scale to an ordinary ground dolomite, and they were successful in producing a clinker which the steelmakers who used it said was superior to any of the clinkers that they obtained from the ordinary calcination of basic in the shaft kiln. It was not found possible to proceed commercially with that development, but it was indicated by those trials, which were made in a small rotary kiln, and also with briquettes in a down-draft kiln, that it was commercially feasible to produce a clinker which had properties that were, in some respects at any rate, better than those of the ordinary clinker produced in the shaft kiln.

I was particularly interested, on a visit to America very shortly after this work had been done, to see that that technique was being operated there, and that much of the basic which was being produced for use in the basic furnaces in the States was made from mixtures very similar to our own, and was giving very good results in basic furnaces. However, with the developing interest in dolomite bricks, this work was continued just a little further in laboratory experiments.

In Dr. Swinden and Dr. Chesters' paper it is indicated that the resistance to a basic slag of a stabilised brick is rather lower than that of a partially or semi-stabilised brick, or of dolomite itself, and it is evident from the data given there that for some positions in the basic open-hearth furnace the partially stabilised brick may present advantages because of its greater slag resistance. It is indicated in the paper that with small additions of clay-about $2\frac{1}{2}$ % of normal ball clay—and $2\frac{1}{2}$ % of normal mill scale it is possible to produce clinker bricks which will remain stable; that is to say, they will not show hydration cracks or any powdering for five or six weeks. That, of course, implies that they will not keep in stock as a stabilised brick will, but it does show that their production can be possible under conditions where they can be used reasonably

Since this work was published, some manufacturers are producing a partially stabilised brick and protecting it from hydration by various methods of coating. At the time when the work was done, some ten or twelve years ago, we investigated the same field to some extent, and we found that the bricks could be protected for a few weeks longer by dipping in a selected wax. That was expensive, and the increased protection given was not very great. During quite early work we did indicate that it was possible to produce, with carefully controlled technique, a partially stabilised brick from the raw dolomite in one operation—that is, by carefully controlling the rate of firing, and keeping the bricks protected, so that they were not carrying much weight besides their own, the shrinkage causing very little deformation; but the better way, in my view, to make the partially stabilised brick is first of all to prepare the partially stabilised clinker and then to make that into brick, using as a vehicle some material containing little or no water.

I am quite sure that this particular field is one which will be developed. It is attracting a good deal of attention in American basic steelmaking circles at the present time, because they, like us, are short of magnesite—not so short as we are, perhaps, but they are short—and very much more attention is being given now in America to the use of the dolomite refractory. The indications in the paper are quite definite, and I think they indicate to manufacturers the direction in which developments might proceed.

The Chairman (Dr. W. H. Hatfield, F.R.S.): We have had three excellent papers. At the Firth-Brown works, in connection with the very large electric-furnace production, we had to do something about refractories, and it is now twenty years since we successfully started using dolomite bricks, as is, I think, well known to many of you. And I can say that the bricks have proved marvellously successful. My colleague, Mr. Dawtrey, collaborating with the refractories people, carried out a most effective piece of work, in which refractory research was combined with steelworks observation, and we solved the problem; magnesite bricks are unnecessary.

When the war was declared I prepared a full report on this matter and placed it with the Steel Control, pointing out and emphasising how unnecessary were the very large magnesite imports for this particular purpose. Therefore I can say now, without fear of contradiction, that I confirm all that has been said. The dolomite

brick has come to stay.

As regards ourselves, our source of supply is one particular firm of refractory makers—General Refractories, I may say. Their production is very limited; they have specialised on production really for specialised electric furnaces, and of course have not available the large plant necessary for dealing with what must be the huge

resources necessary for the basic process.

It is very interesting to see how and where the X-ray method of attack comes into play, and I think we have had, in the first paper, a very interesting exhibition of the utility of that method of approach. The subject divides itself into electric-furnace practice, which is of great importance to Sheffield, and basic practice, which will become more important, and it behoves us all to take the utmost interest in these basic refractories.

Dr. R. J. Sarjant (Messrs. Hadfields, Ltd., Sheffield): I have looked into these papers with a great deal of interest, and it occurs to me that in the first paper, Dr. Rait's, there is a certain point which, when looked at in the light of Dr. Rees' note, raises a matter of considerable interest on the subject. The stabilisation question, in Dr. Rait's work, was of course confined mainly to the silicates which combined with lime and removed the free lime, but in Dr. Rees' paper there is the incorporation of iron oxide. In Table IV., con-

taining the full list of the mineral compositions calculated by Dr. Rait, there is a very interesting mineral called brownmillerite. Further, if you look at Dr. Rees' semi-stabilised dolomite in the same way you find that when these minerals are calculated for that particular mixture the periclase is 35%, the free lime 33%, the brownmillerite 15.4% and the tricalcium silicate 16%. The point that I am going to throw out for discussion and, I hope, controversy is that there is some importance in the presence of the brownmillerite in moderate proportion.

We know that in an open-hearth furnace bottom, where there is an infiltration of slag containing particularly iron oxide, there is stabilisation, and we have found, when we have been examining the open-hearth bottoms that have become stabilised by the infiltration of slaggy materials, that there is always that presence of the brownmillerite; it seems to me that some attention should be devoted to the development of just the right amount of brownmillerite which might act as the fluxing material to coat the grains

and give the semi-stabilisation.

It is also interesting that the main conclusion of Dr. Rait's paper is that the methods used in making dolomite bricks are just the right

With regard to the paper dealing with the dolomite brick, of course, I think we all realise now that dolomite bricks can be used, particularly the fully stabilised type, to displace magnesite bricks entirely in melting furnaces, either the basic open-hearth or the electric furnace. There is no longer the fear on the part of the steelmaker that he must have a safety margin of magnesite, because it has been quite clearly proved in the paper (and I think many steelmakers now are able to give their experience in support of that view) that the dolomite brick has come as a permanent feature now of the open-hearth furnace. I am very glad to note that Dr. Swinden looked to the day, after the war, when we should still be using dolomite bricks. By that time, no doubt, thanks to the development of the technical aspects, the dolomite brick manufacturer will have still further improved the brick, and we shall not be in the unfortunate position of having to go back to importing magnesite bricks. It is a matter, I think, of a certain amount of importance, nationally and economically, and after the war it will no doubt be a matter to which a good deal of attention must be given. Some may want to have the magnesite back, but as far as the hearth is concerned, where the brick does not come in contact with the atmosphere in the furnace, the dolomite brick is perfectly satisfactory. The degree of stabilisation is now adequate, and could be accepted.

One further valuable use of stabilised dolomite materials, which is possibly not realised in the industry as it might be, is in reheatingfurnace hearths. Both the stabilised dolomite brick and monolithic mixtures which are made from stabilised dolomite are perfectly satisfactory in those hearths. We now have some reheating furnaces

which are made up of monolithic mixtures of that kind. They have been in operation only a few months, but they are giving a very promising life. I think further developments are possible in the other parts of the furnace. We have not explored, to anything like the degree that we should, the possibilities of the use of basic materials in furnaces other than melting furnaces.

Mr. A. L. Bradley (Refractory Brick Company of England, Ltd.): When we started the stabilisation of dolomite some six or seven years ago, we were helped to a very large extent by Dr. Chesters, and by Dr. Jay in the X-ray department of the Central Research Department of The United Steel Companies, and I am very gratified to find that Dr. Rait has confirmed all the original conclusions that were obtained from this early work.

There are certain questions that I would like to put to Dr. Rait with reference to the technique that he employed in his investigation. In particular I am interested to know at what temperature these clinkers were fired and whether they were refired or not. In his paper he mentions a firing temperature of 1500° C., and I am very pleased, if that is correct, to note that complete stabilisation of

dolomite clinker can be obtained at 1500° C.

With regard to the question of constitution, I wonder how much glass is really formed in a commercial dolomite clinker. In his paper Dr. Rait mentions that because the amount of free lime found experimentally is in reasonable relationship to the calculated theoretical amount, the glass contained must be relatively little. On the other hand, if you take the primary phases of crystallisation from the quinternary system lime, magnesia, tricalcium silicate, tricalcium aluminate and brownmillerite, magnesia and tricalcium silicate and free lime will probably crystallise first, leaving brownmillerite and tricalcium aluminate mainly in the liquid phase. Since these latter compounds are not found in the X-ray determination, I would suggest that they are mainly present in the liquid or glassy phase, and since they are in reasonable proportions in the clinker, the glass content must be at least equivalent to the amount of these compounds. Some means of determining the quantity of glass, not only in dolomite refractories but in other refractories also, is urgently required, and the correlation of the glass content with the physical properties of the bricks would be a useful piece of research work.

On the subject of the dissociation of tricalcium silicate, I would like to refer to the work of Carlson, who did much work on this subject with reference to Portland cement. He found that old clinker, say three or four years old, when finely ground tended to break down a good deal more rapidly than fresh clinker. If lump material is used, the rate of dissociation is considerably

¹ E. T. Carlson, Bureau of Standards Journal of Research, 1931, vol. 7, p. 893.

slower, and I think that if a brick were taken, then the rate would be slower still. It would appear that the surface area of the particles and the presence of the product of dissociation are factors which greatly influence this phenomenon, and that the investigation of this provides a useful field for further academic research.

Dr. Rait has mentioned the use of stabilisers added to prevent the inversion of dicalcium silicate. We have discovered five or six compounds which will do this, but, as yet, there is no theoretical explanation as to how these inhibitors function. Bates and Klein ¹ mentioned that chromium oxide and phosphates can effect this stabilisation, and it would be interesting to find out if these compounds or elements of these compounds enter into the dicalcium silicate lattice and prevent it from inverting from the β to the γ form. The investigation of this inversion and its prevention is a further fruitful field for academic research which might provide some useful information for the manufacturers of dolomite clinker.

In conclusion, and referring to the stabilised dolomite bricks that have disintegrated either in the furnace or in storage, which some unfortunate steelmakers have encountered, I can say that in every case that I have examined this disintegration has been entirely due to the fault of the brickmaker concerned in not firing his brick to the correct temperature. As shown by Dr. Rait, if he fired his tricalcium silicate to 1400° C. there was no free lime present and consequently no disintegration.

Mr. P. W. Wood (Consett Iron Co., Ltd., Consett, Co. Durham): We at Consett have been using stabilised dolomite bricks for five years, I think, and, what will interest those who understand the steel furnace and its operations, we have not had a breakout of any consequence as a result of using those bricks. I think that is one point in their favour.

The weakness, if any, of them is that you cannot expose them above the slag-line to any extent. They do not stand up as the old magnesite bricks did. Please understand that I am a steelmaker, and not a metallurgist or a brickmaker in any shape or form; I think that Dr. Hatfield asked me to speak because of my practical

experience.

We have tried the use of stabilised dolomite as a fettling material, and I am sorry to say that it is not a success. In the past we have looked at the analysis of an ordinary dead-burnt dolomite with disfavour if it showed more than 4% of silica, and I think we were quite right. If there is more than 4% of silica in the dead-burnt dolomite it probably has a low refractoriness, and for this same reason I cannot see why this material—call it what you like—which has 15% of silica can have anything else but a low refractoriness. When it comes in contact with basic slag it probably absorbs iron oxide, or

¹ P. H. Bates and A. A. Klein, U.S. Bureau of Standards, 1917, Technological Paper No. 78.

lime (I am not quite sure which), but certainly it seems to me to be a failure as a fettling material.

Dr. D. F. Marshall (Park Gate Iron and Steel Co., Ltd., Rotherham): I think we started experimenting with stabilised dolomite bricks about the same time as Dr. Swinden. From 1936 onwards our practice developed, until at the outbreak of hostilities we had completely dispensed with the use of magnesite bricks in the hearths of our nine basic open-hearth furnaces. Recently we extended the use of stabilised dolomite bricks by building them into the hearth of a 400-ton tilting mixer. We are quite satisfied with the results of this substitution of dolomite bricks for magnesite, and the number of breakouts has certainly not increased. Economically the substitution is sound, particularly in view of the high proportion of recoveries obtained when a hearth is replaced.

In conclusion, I should like to congratulate Dr. Rait on his excellent application of modern scientific apparatus to the solution

of an important industrial problem.

- Dr. J. H. Chesters (The United Steel Companies, Ltd., Stocksbridge, near Sheffield): I should like to congratulate Dr. Rait, Mr. Goldschmidt and Mr. Green upon a very excellent piece of academic research, and hope that the British Refractories Research Association will now go on and give equally serious attention to the question of the thermal-shock resistance of dolomite bricks. A great deal of work has been done on this subject by the Refractory Brick Company, but their academic work has inevitably been limited by the demands of production. The work that they have done suggests that a considerable improvement can be effected by the addition of suitable grades of chrome and magnesite, but that the advantages of such additions tend to be lost in service, owing to the ease with which the brick becomes vitrified. In dolomite bricks cracks formed by thermal shock tend to spread indefinitely, not stopping on reaching a coarse grain as they do in a grogged fireclay brick. If some method could be devised of stopping the cracks from spreading, using a technique that would be effective even after high-temperature use, then a big step forward would have been made. Work done in conjunction with the University of Leeds shows that dolomite bricks have a high modulus of rigidity even at 900° C., and a study of the effect of the stabilisers, magnesite and chrome additions. &c., on the rigidity might therefore prove quite fruitful.
- Mr. T. R. Lynam (Oughtibridge Silica Firebrick Co., Ltd., Oughtibridge, near Sheffield): There is only one point which I should like to raise, and that is with regard to Mr. Bradley's concluding remark, a most unkind one, to the effect that if there is any trouble with dolomite bricks it is due to the manufacture of the bricks. Mr. Bradley knows that some considerable time has been

spent in discussing this problem of the failure of dolomite bricks, and he knows that all the brickmakers, with the possible exception of the Refractory Brick Company, are against the opinion that the fault is due to the manufacture of the bricks entirely. I may point out that dolomite clinker has been delivered which, on occasions, contained a fairly high proportion of free lime.

Mr. H. Parnham (General Refractories, Ltd., Worksop): The paper by Dr. Rees, whilst it is short, is very interesting to me, because I am connected closely with the manufacture of the semistable type of brick. What interested me most, I think, were the experiments carried out, both by Dr. Rees in this country and in America, on producing experimentally a clinker which we could call uniform. The clinker, as we know, is fired to-day in shaft kilns, and generally it is very good, but occasionally, as you steel people well know, it can be very bad. Well, I think that a considerable advance would be made in this country if we could get a clinker which had received uniform heat treatment.

Further in connection with the use of the semi-stabilised type of brick, I can only say that bricks have been kept in stock for six months, and experimental bricks are already in their twelfth month, and both are resistant to hydration, so I think the industry can rely on it that these bricks will be satisfactory in storage for at least

nine months. That is according to present information.

Dr. Sarjant remarked on the importance of brownmillerite being present in dolomite bottoms in order to give good service; that is certainly a good point, but it shows very clearly that brownmillerite, whilst it does not affect the 100% basic, plays havoc with the stable type of dolomite, owing, of course, to the formation of a low-melting slag.

Mr. K. Headlam-Morley (Secretary, The Iron and Steel Institute; Deputy Controller, Chrome Ore and Magnesite Control): I think it may be interesting, from the point of view of consumption, to tell you that we at the Chrome Ore and Magnesite Control have been following the development of dolomite bricks with great interest, inasmuch as we are concerned in saving shipping space by cutting down imports. I do not want to quote actual figures, but, roughly speaking, half of the pre-war consumption of magnesite only is now being used, although steel production has certainly not dropped. The actual saving is greater than this, because there was a tendency for the consumption per ton of steel to increase. Of that economy, about 10,000 tons a year is represented by the substitution of dolomite bricks for magnesite bricks.

A point which, although not of immediate interest from the war angle (though it does affect that also), should not be neglected is that the balance of magnesite now being consumed is within the productive capacity of this country. That raises interesting reflections on what the position may be after the war; I hope that,

whatever happens, this country will never again get into the position

of being dependent on imported basic refractories.

At a meeting one day last week which I had the pleasure of attending, and at which representatives of certain steel companies were also present, there was a most interesting discussion on the use of basic refractories. It became apparent that certain companies were using stabilised dolomite bricks in positions for which they were clearly unsuitable. That was largely due to an excess of zeal in attempting to economise in the use of magnesite bricks. Such zeal is highly creditable, but bricks should only be used for the purpose for which they are appropriate; wasteful use of British-produced materials does not help; the common-sense attitude is the right one and in fact the most economical refractory practice is also at this moment of the greatest service to the country.

Dr. T. Swinden: Mr. Headlam-Morley has taken just the two points that I had intended to mention. First, the point raised by Mr. Lynam in comment on Mr. Bradley's contribution is, I think, being taken care of in the best possible way, as has been said, by the dolomite brick manufacturers getting together by way of an informal committee. There is on the table here a statement from their last meeting, showing just the problems that they are tackling, how they have shared them out, and how quickly they will be dealt with. The other point is that mentioned by Dr. Sarjant, namely, the post-war economics of this question of dolomite bricks. As Mr. Headlam-Morley has said, I see no reason whatever why this business, of making both fully stable and semi-stable dolomite bricks, should not be put on a really sound foundation as a post-war business, and I think it will be to the benefit of everyone concerned in this country.

Dr. W. J. Rees: I should like to make a very brief reference to two quite short paragraphs in the paper by Dr. Swinden and Dr. Chesters, more with a view to possible post-war use and to indicate that work recorded there should not be forgotten. Some years ago a student of mine, Mr. Tyler, was prospecting in the Anglo-Egyptian Sudan, and he found a whole hill of magnesian talc rock. He came back with specimens of this, with instructions from his firm who had sent him out there to see whether any commercial use could be made of it, and we at once started experimental work on the production of a stable dolomite brick, made roughly half-and-half of this sudanite (the name given to this magnesian talc rock) and dolomite, first in the laboratory and later in conjunction with the Steetley Lime and Basic Co., Ltd. Dr. Swinden and Dr. Chesters are good enough to give definite credit to that work in the statement that the stable dolomite brick made to-day is essentially the same in composition as the one that Tyler and I made on a small commercial scale in 1934. When this war is over there may be opportunities of bringing this Sudan material over again. It has certain

advantages over a material such as serpentine, because when it is used it provides not only the stabiliser but also some magnesia, and therefore produces something a little more refractory than the ordinary stable dolomite brick. Some of these things get lost in the literature, and I wish to point out the possibility of its post-war development.

- Mr. W. H. BAILEY (Messrs. Kayser, Ellison and Co., Ltd., Sheffield): Mr. Wood, from Consett, in his remarks said he was a steelmaker, and I believe he is the only Member who has spoken from that viewpoint. There are others at this Meeting who are interested in steelmaking, and I as one of them am rather disturbed at his remarks concerning stabilised dolomite in use. It is arranged that we should have a certain allocation of this material as a stand-by for emergencies, and I am wondering what is our position as steelmakers, relying on this material at a time when no other supplies are available, if, as he says, it is not satisfactory or as good as ordinary ground basic.
- Dr. J. H. Chesters: The idea of supplying stabilised dolomite clinker as a reserve for steelworks was to ensure that in the event of their not being able to obtain basic, for instance, owing to snowfalls or enemy action, it would still be possible to carry on fettling. It has not been suggested that stabilised clinker would be better for this purpose than basic, much less than magnesite, but merely that it would do the job and tide a works over a period when otherwise they would have to shut down their furnaces. Basic stored in air-tight drums would be equally effective as a reserve, but the problem of obtaining so large a number of tins might be a serious one.
- Mr. A. L. Bradley: If I may make one remark with reference to Mr. Wood's experience with stabilised dolomite clinker as a fettling material, I would like to draw an analogy. If a hole in a piece of steel is filled with a material having physical properties different from those of the original sample and is then subjected to corrosion. it will be found that this area is liable to severe attack. I believe that part of the trouble experienced with stabilised dolomite clinker for fettling is that the material has been applied in an incorrect grading, resulting in different physical properties and consequently localised attack in the hearth of the furnace.

OPEN-HEARTH ROOFS, INCLUDING TEMPERATURE CONTROL.

Dr. T. Swinden introduced the subject of Open-Hearth Roofs, including Temperature Control. He said: It is not an easy matter to introduce a comprehensive paper of this character, but it is hoped that the three subsequent speakers will be able to bring out its salient points for your benefit.

The circumstances under which the work came to be undertaken have been set out in the Second Report on Refractory Materials (Section B), and, except for the fact that this paper was printed before the Second Report had been prepared, it could very usefully have

been included in the Report.

I would merely like to emphasise the further example provided by this paper of co-operative research in the very best meaning of that term. The open-hearth roof so often represents the limit of life before repairs are necessary, and in any case it is a very important factor in repair costs. It was with pleasure therefore that my Company offered to provide a furnace complete with elaborate pyrometric equipment and provide facilities to the British Refractories Research Association and to collaborate in the fullest possible way in the observational work during the whole period while the furnace was being gassed, until it finally went out of commission. Further valuable work was done by post mortem examinations of representative bricks, which aspect will be dealt with by Mr. Hugill. Not the least important factor, however, was that the Oughtibridge Silica Firebrick Co. agreed to supply this roof and to allow complete facilities for examining and recording the manufacture of the necessary blocks.

It would be difficult to imagine a more complete co-operative effort, and there is no doubt that the paper provides us with a deeper insight than we have ever had before into the factors influencing

the durability of the roofs of basic open-hearth furnaces.

It is particularly heartening to think that, notwithstanding the stress of war conditions, it is possible to carry out work of this kind, and the value of the work should have a direct reflection on output as a contribution to the war effort. After all, open-hearth steel-making is the backbone of our steel production, and the three vital factors which will in due course help us to put open-hearth steel-making on a more scientific basis are:

(a) Greater stability of the furnace structure.

(b) Temperature control.

(c) Slag control.

It is factor (a) which is so important, in demanding skill in the handling of a furnace, and which is still one of the most serious difficulties in maintaining complete reproducibility of results. This paper makes some contribution in the direction of greater stability of furnace construction. The other items are outside the purview of this Meeting, but it may not be out of place to recall that at the Meeting of the Institute two weeks ago the Third Report of the Liquid Steel Temperature Sub-Committee ¹ placed before the Members a most valuable statement, again typical of the co-operative spirit in research now prevailing in this country, showing that at last it is possible to determine liquid steel temperatures during the course of the making of open-hearth steel. This will in turn undoubtedly lead to better slag control and a more scientific operation of the whole process.

¹ Journal of the Iron and Steel Institute, 1942, No. I., p. 213 p (this volume).

As you know, other groups of people are working on the factors leading to a better understanding of the physical chemistry of the process, and I feel that during the last few years we have made tremendous strides towards an improvement in this vital process of steelmaking.

- Mr. T. R. Lynam (Oughtibridge Silica Firebrick Co., Ltd., Oughtibridge, near Sheffield) then introduced "Low-Temperature Roof Pyrometry.—Thermocouple Control in Heating up Furnaces" (Basis: "A Co-operative Investigation of the Factors influencing the Durability of the Roofs of Basic Open-Hearth Furnaces," Journal of The Iron and Steel Institute, 1941, No. II., pp. 203 P-262 P).
- Mr. A. E. Dodd (British Refractories Research Association, Stoke-on-Trent) followed with an introduction of "High-Temperature Roof Pyrometry.—The Use of Roof Pyrometers in Maturing the Roof and Increasing its Life" (Basis: The above-mentioned paper on Basic Open-Hearth Roofs).
- Mr. W. Hughl (British Refractories Research Association, Stoke-on-Trent) dealt with "The Microstructure of Used Roof Bricks" (Basis: Section VI. of the above-mentioned paper on Basic Open-Hearth Roofs).
- Dr. A. H. B. Cross (Brown-Firth Research Laboratories, Sheffield): The work which has been done on the basic open-hearth furnace roof is of particular interest to all steelmakers, and not least to acid steelmakers. My Company has made quite an extensive study of silica refractories in the acid open-hearth furnace, and it is a point of great interest that the structural and even the mineralogical changes which the acid open-hearth roof silica brick indicates are very closely in line with those recorded in this paper. Outstanding points of interest are, first, that in our experience there is no pick-up of lime in the acid furnace, and, secondly, the existence of sulphur compounds in the cooler portions of the brick seems to be entirely insignificant in the acid furnace. However, the colour changes typical of the existence of those compounds in the basic-furnace brick still occur in the acid-furnace brick, and are apparently due to small amounts of sulphur, which can be found in the majority of refractory materials. The striking thing which is revealed in the paper, and which can be even more strikingly demonstrated by an extension of the work to other parts of the furnace, is the remarkable stability of siliceous materials when they are contaminated by high proportions of iron oxides and other adulterants from the furnace atmosphere or the slag. Reference is made in the paper to the high refractoriness of the zones containing large proportions of iron oxide, and it has been shown quite effectively that this is partly a structural characteristic, that if the structure of that

brick is destroyed by reducing the solid material to powder and rebonding it, then that high refractoriness is not maintained. In other words, it is attributed to a lack of homogeneity. And the same sort of thing is found in connection with acid-furnace bricks. striking instance is presented if one carries investigation to other parts of the furnace, for instance, the gas port, where there may be enormous accumulations of iron oxide. In one case recorded that was as much as 23%, over 17% of which was ferrous oxide. One can still find refractoriness above 1700° C. These observations must cause one to think very carefully just how many of the failures of silica bricks in the open-hearth furnace are due to circumstances beyond the control of the melter or how far they are due to the characteristics of the bricks or the raw materials; in many cases where the brick has developed into a seasoned condition in a normal manner it certainly seems that these failures of silica refractories are due to factors external to the brick.

Mr. D. C. Muir (Consett Iron Co., Ltd., Consett, Co. Durham): This work has definitely proved a matter which has been a source of contention for many years—that there is such a thing as the

maturing of an open-hearth roof.

We at Consett have proved it to our own satisfaction for many years by close observation of the roofs, and by keeping careful records of the times when the roofs were burnt and of the total life of each roof, and we found definitely that if a roof was burnt very early in its life, in the first or second week, then that roof did not last very long. On the other hand, if it was carefully glazed for the first or second week we could safely say that the roof would have a good life. The work done in this piece of co-operative research has shown the reason for this, in that striking change in the temperature gradient through the roof after two weeks, showing that the inside portions of the roof bricks have a greatly increased conductivity and are, therefore, not so susceptible to overheating.

That point, I think, is worthy of consideration by open-hearth managers, in that it may be advisable to go easy with the furnace for the first two weeks and gain a few weeks' extra life in a campaign, rather than try to get two extra charges out of the first fortnight

while the furnace is working well, and risk burning the roof.

A new furnace has a roof like the sketch in Fig. A (a), and after a fortnight's careful working it should be glazed as shown in Fig. A (b), exposing a minimum surface to the furnace gases and having a glazed surface which reflects the heat. If the roof is burnt it becomes like Fig. A (c) and eventually like Fig. A (d). It is obvious that if the roof is in this state, the surface area exposed to the heat may be two or three times that on a well-glazed roof, and once the roof is burnt in this fashion it will continue to wear rapidly.

Another point brought to my mind by Dr. Cross's remarks, and for which I myself have at present no satisfactory explanation, is the different manner in which acid roofs and basic roofs are

affected when they are burnt. Our experience at Consett is that when an acid roof is burnt you get a sharp-edged hole like Fig. A (e), and for a few months the burnt area will remain more or less unchanged, although it may deepen. If you get a similar burn in a basic roof the edges of the area may start well-defined, but we find that the area gradually extends, the edges become smoothed out, and the burnt area seems to spread like a disease over a large area

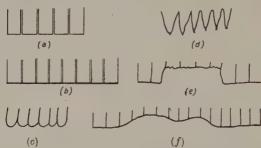


Fig. A.—Open-Hearth Furnace Roof Bricks. Effect of burning the roof.

of the roof, as in Fig. A (f). Although we have no satisfactory explanation for this yet, we have no doubt that a little more co-

operative research will find the reason for it.

I should like to conclude by adding to the remarks of Dr. Swinden and others to-night concerning the amazing amount of work that has been got through in a very short time by co-operative research on refractories. This piece of work was the start of it, and we now have committees engaged in co-operative research on magnesite, chrome-magnesite and dolomite bricks, and the speed with which the work is done is really astounding.

Dr. T. SWINDEN: I would like to pay tribute to the several contributors to this work who have not had the opportunity of speaking; to Dr. Chesters and Mr. Howie, of the Refractories Section of the Central Research Laboratory of The United Steel Companies, Ltd.; to Dr. Jay, also of the Central Research Laboratory, who contributed the Section on the X-ray studies particularly; to Messrs. Doyle, Collins and Pluck, of Messrs. Steel, Peech and Tozer, who contributed those Sections on the furnace and pyrometry installation, draught conditions, details of repairs, and so forth; also to Mr. Methley, of Messrs. Steel, Peech and Tozer, who collaborated in the examination of samples taken from the roof at the end of the campaign.

Finally I would mention the very deep interest which the late Mr. Percival Smith took in this work and in everything to do with the open-hearth furnace. Wherever open-hearth furnace problems are being discussed his name will be in our minds, and we revere his

memory.

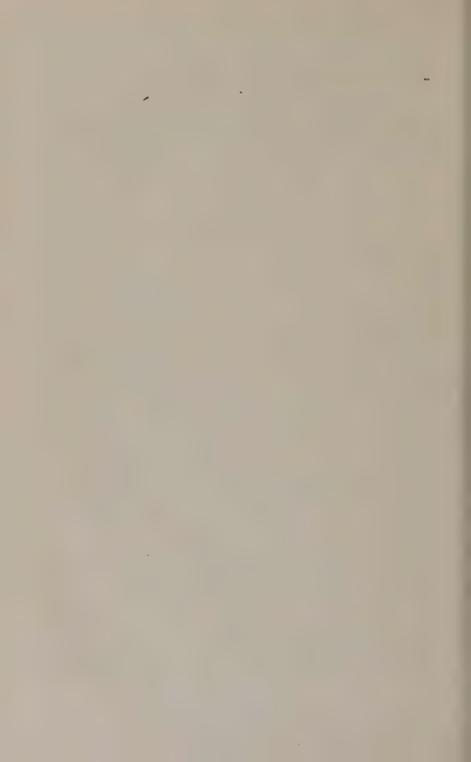
SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

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The Editor has been assisted in the preparation of this Survey by R. A. RONNEBECK.



REFRACTORY MATERIALS

Phase-Equilibrium Data in the Manufacture of Refractories. R. E. Birch. (Journal of the American Ceramic Society, 1941, vol. 24, Sept., pp. 271–280). The author discusses the application of equilibrium diagrams to the manufacture of refractories. With regard to silica bricks he refers mainly to Grieg's work on the immiscibility of lime-silica melts and to the effect of the alumina and other oxides on the melting point of lime-silica mixtures with up to about 27.5% of lime. The refractoriness-under-load of silica and of magnesite refractories are compared and the effect of the presence of such oxides as CaO, $\mathrm{Al_2O_3}$, $\mathrm{SiO_2}$ and MgO on the properties of magnesite bricks is explained by reference to diagrams showing the amount of liquid phase present at different temperatures. In conclusion the behaviour of dolomite, chromite, forsterite and alumina-silica refractories is deduced from the appropriate

equilibrium diagrams.

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Description of Hot Modulus of Rupture and Hot-Crushing-Strength Tests and Discussion of Results. E. B. Hunt and R. S. Bradley. (Bulletin of the American Ceramic Society, 1941, vol. 20, Aug., pp. 267–269). The authors describe the equipment and test procedures used to make modulus of rupture and crushing tests on refractory specimens at high temperatures. The apparatus was designed to withstand a total load of 11 tons on either of two test specimens at temperatures up to 2900° F. Six varieties of high-quality refractory bricks were tested. For the types tested, the results indicate a general tendency for the crushing strength and modulus of rupture to remain relatively constant from room temperature to approximately 1800° F. In most cases the strength was somewhat higher in the range 1800-2000° F. The specimens in the crushing and modulus of rupture tests failed below 1800° F. in the same manner as in the tests at room temperature, whereas in the tests at above 2000° F. they became compressed or were bent to some extent before they failed.

Temperature Gradients Through Composite Carbon Columns and Their Application to Blast-Furnace Linings. F. J. Vosburgh and M. R. Hatfield. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1363: Metals Technology, 1941, vol. 8, Sept.). The authors discuss the water-cooling of the shell plates of blast-furnaces which are lined with carbon blocks, and describe a laboratory investigation the object of which was to determine the temperature which the shell plates of a carbon-block-lined blast-furnace might reach when the furnace was operated at temperatures up to 3000° F. The apparatus used consisted of a heating element made of a horizontal carbon tube 30 in. long \times $2\frac{5}{8}$ in.

outside dia. The blast-furnace lining was represented by a composite column of carbon blocks 31 in. square and 29 in. high, with the lower end shaped to make a close fit on the carbon tube. A steel plate $3\frac{1}{2} \times 3\frac{1}{2} \times 1$ in, rested on top of the column and represented the furnace shell plate. The whole of the test column was surrounded by 9 in. of charcoal particles in a box, but the upper surface of the top plate was left exposed. Holes with optical pyrometers were arranged for taking temperatures at the lower and hotter portion of the column, and thermocouples were used to take temperatures of the steel plate and the cooler portion of the column. Temperature gradient curves for different grades of carbon blocks are presented, and it was found that the thermal conductivity at room temperature of a suitable grade was 2 B.Th.U. per sq. ft. per degree Fahrenheit per hr. per ft. The data obtained led to the conclusion that with a furnace lined with carbon up to the mantel working at as high a temperature as 3000° F. it would not be necessary normally to cool the shell with water, but it might be advisable to have facilities for emergency cooling with water or with an air blast.

Abrasives in the Rôle of Super-Refractories. H. C. Fisher. (Metal Progress, 1941, vol. 40, Aug., pp. 177–182). The author discusses the properties of a number of materials which are both abrasive and highly refractory; these include different grades of fused alumina, silicon carbide and electrically sintered magnesia. He also deals with some refractory minerals, including corundum, bauxite, diaspore, sillimanite, and alusite, kyanite, kaolin, zirconium oxide and silicate, chromite and silica. A table is presented in which the properties of these materials are compared by giving them relative classification numbers.

A Co-operative Investigation of the Factors Influencing the Durability of the Roofs of Basic Open-Hearth Furnaces. The Open-Hearth Refractories Joint Panel. (Journal of the Iron and Steel Institute, 1941, No. II., pp. 203 P-262 P). This is a report of an investigation by the Open-Hearth Refractories Joint Panel working under the ægis of the Iron and Steel Industrial Research Council and the Council of the British Refractories Research Association. The results of observational work on the roof of a basic open-hearth steel furnace are reported. The observations commenced with the raw materials from which the silica roof was made, and ended with laboratory work on samples taken from the roof at the close of the campaign. During the campaign itself a pyrometric record was made of the temperature at the surface and at various levels within the roof.

The raw quartzite contained a proportion of comparatively large grains which were more readily converted than the remainder of the rock; this was attributed to strain within the lattice. The amount of tridymite produced in the fired product was to some

extent dependent on the fineness of grinding.

On warming-up an open-hearth furnace care must be taken in

controlling the pull of the stack; if the stack damper is suddenly opened before gassing, the temperature of the roof may fall $200-300^{\circ}$ C. in a few minutes. The readings of the radiation pyrometer focused on the roof in a large measure confirm the findings of American workers; in particular, temperature fluctuations of the order of 300° C. occurred during charging. In addition to these violent changes in temperature, however, fluctuations of about 50° C. occurred at each reversal; these variations were substantiated by thermocouple readings.

The pyrometer record served to show that during the first two weeks of the campaign the temperature gradient near the hot face became greatly modified; this effect is assumed to be associated with the "seasoning" of the roof. Other important factors bound up with seasoning may be the marked decrease in porosity and the slight increase in refractoriness of the cristobalite zone. At a later stage in the campaign the roof became hotter at the tapping than

at the charging side.

Sampling of the dust and slag carried by the waste gases confirmed that the furnace atmosphere is most dusty during charging; at this period the dust consists mainly of lime, but during melting

iron oxide preponderates.

The zonal appearance of the used roof bricks was normal, but analysis showed that the iron oxide content of the cristobalite zone was a little higher than that of the tridymite zone, while the lime had concentrated nearer to the hot face than the pale-yellow zone usually assigned to it. This zone was almost impermeable, owing to a narrow band of calcareous glass; its refractoriness was 1640° C. when powdered and rebonded. Several samples had cracked laterally in the region of this glassy band.

The high temperature attained by the brickwork when a charge foams and the deleterious influence of foaming on the refractories

have been confirmed.

Basic Open Hearth. J. H. Chesters. (Iron Age, 1941, vol. 148, Aug. 7, pp. 37–40, 106; Aug. 14, pp. 39–41; Aug. 21, pp. 52–58). Conclusion of a series of articles (see Journ. I. and S.I., 1941, No. II., p. 107 A). The author describes the construction and fettling of basic open-hearth furnace bottoms, the preparation of ganister for lining launders, the design and causes of failure of gas and air uptakes, slag pockets, checker bricks and checker-chamber linings for furnaces of about 80 tons. He points out some of the differences between British and American practice.

The Effect of Increasing Heat Treatment on Properties of Diatomaceous Insulating Brick. H. Oliver and J. S. Rigby. (Transactions of the British Ceramic Society, 1941, vol. 40, Sept., pp. 335–358). The authors studied the effect of subjecting diatomaceous insulating bricks to increasing temperatures on their physical properties. They arrived at the following conclusions: (1) This type of product begins to shrink with increasing severity above

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950° C. (2) The bulk density is affected in a similar manner, an increase of approximately 15% being obtainable. (3) The porosity is very slightly affected by increasing the temperature. (4) The true specific gravity gradually increases with increasing temperature. (5) The thermal expansion is generally low, but increases in degree from 1000° C. upwards. The curves give indications of increased formation of tridymite at the higher temperatures of refiring. (6) Permeability results are affected more by variation in texture than by heat treatment. (7) The thermal conductivity values are affected by heat treatment to an extent of about 30% increase after refiring to 1050° C.; it is suggested that this is related to the increase in bulk density. (8) The effect of heating one face of a normally fired diatomaceous product up to 1050° C. was studied. and it was found that it took 24 hr. longer heating than the normal testing period to attain equilibrium; the increase in thermal conductivity during the 24 hr. was 3.7%. This suggested that it might be possible to use this product at a hot-face temperature of 1050° C. without serious loss of efficiency. (9) The economic possibilities of using normally fired diatomaceous bricks at temperatures up to 1050° C. compared with those of using material previously fired to 1050° C. were considered; the advantage lay with the former. The possible advantages of raising the limiting hot-face temperature of the normally fired material from 900° to 1050° C. were also examined.

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Large Modern Reciprocating Engines in Iron and Steel Works and Mining Plants. L. Engel. (Stahl und Eisen, 1940, vol. 60, Oct. 10, pp. 897-904). The author reviews the development of large reciprocating engines in the iron, steel and mining industries. He compares the capital costs of gas-engine-driven and steamengine-driven electric power stations and gives some particulars of a large gas-engine-driven blower installed recently at Witkowitz and of a five-cylinder reversing steam engine for driving a four-high plate-mill stand with rolls 5200 mm. long. The latter engine has some unusual features, in that the five cylinders (630 mm. in dia. and 950 mm. stroke) are side by side and drive a common crankshaft; it operates at a high speed (max. 270 r.p.m.), and it is equipped with an automatic speed regulator and a control operated by oil under pressure. The capital costs and efficiencies of gas engines and reciprocating steam engines for compressing longdistance gas, for compressing air for mine ventilation and for winding purposes at collieries are compared and discussed.

Ways and Means of Increasing the Capacity of Existing Gas-Engine-Driven Power Stations. L. Maduschka. (Stahl und Eisen, 1940, vol. 60, Oct. 24, pp. 941–946). The author makes recomFUEL. 5 A

mendations for increasing the efficiency of large gas engines used in

steelworks power stations.

Steam Turbine Practice in Steelworks. A. C. Hirst. (Overseas Engineer, 1941, vol. 14, Sept., pp. 246–249). The author reviews some of the special constructional features of the design generally applicable to steelworks' turbines of the straight condensing, passout, back-pressure or mixed-pressure type, manufactured by an important English company, which ensure that they will be able to stand up to very severe service conditions.

Coal for By-Product Coking. J. D. Doherty. (American Gas Association: Steel, 1941, vol. 109, July 28, pp. 68–72). The author discusses some factors affecting the selection of coking coals in

accordance with American practice.

Some Functions of Coke in Blast-Furnaces. M. A. Mayers. (Blast Furnace and Steel Plant, 1941, vol. 29, July, pp. 705-709). In this discussion of the relation of the physical and chemical properties of coke to the operation of a blast-furnace, the author explains why the maximum temperature attained anywhere in the combustion zone decreases with increasing reactivity of the coke, and that the belief that a highly reactive coke will burn more rapidly in a blast-furnace and produce a higher temperature than a less reactive coke is probably erroneous. It is pointed out that the range of coke consumption rates observed in practice is closely matched by the ratio of coke to iron in a mixture where the void volume of the coke is just filled up with burden. This suggests that the principal factor governing the operation of a furnace may be the requirement that the coke should provide just sufficient free space to support the burden, and that the departures from smooth operation normally observed may be due to small changes in the volume of open space. A method of increasing the uniformity of the quality of coke is suggested. Most fluctuations in coke quality are due to fluctuations in the composition of the coal supplied to the ovens, and, where ovens are supplied from a number of mines, more attention should be paid to mixing and piling the coal for storage and to the method of removal from storage. For instance, each truck load could be spread over a large area, one on top of another, so that when the coal is picked up from the ends of the pile for charging in the ovens the charge is made up of coal from several different trucks. The same principle could also be applied to coke. The more careful operation of coal- and coke-handling equipment can lead not only to smooth blast-furnace operation, but also to more uniformity in the quality of the products of the steel furnace and the rolling mill.

The Relation of Coke Properties to Blast-Furnace Performance: An Application of Statistical Methods of Correlation. M. A. Mayers and H. G. Landau. (American Institute of Mining and Metallurgical Engineers, 1941, Preprint). The authors explain a method of analysing blast-furnace operational data for the purpose of deter-

mining the correlationships which exist between some of the variable factors affecting the production of pig iron. An example of the application of the method is given in which it is used to analyse the data presented in a paper on the influence of coke quality on blast-furnace operations by Brooke, Walshaw and Lee (see Journ. I. and S.I., 1936, No. II., p. 287 P). The results are given in the form of equations which express: (a) The dependence of the coke consumption on the shatter index; (b) the dependence of the blast temperature on the coke shatter index; (c) the dependence of the silicon content of the iron on the coke shatter index; and (d) the relation between the shatter index and the properties of the coking coal.

The Treatment by Electrolysis of Weak Ammonia Liquors Produced in By-Product Coke Plants. P. J. Wilson, jun., J. H. Wells and J. Coull. (Electrochemical Society, 1941, Preprint No. 80-21). The authors describe some experiments with an electrolytic cell for oxidising the organic matter in weak ammonia liquor arising from coke-oven by-product plants. The body of the cell was of welded steel, which, with five steel plates, formed the cathodes. Of the many materials tried as anodes, only graphite or lead coated with lead peroxide was satisfactory. For the elimination of phenols only graphite cathodes can be used. The experiments demonstrated that electrolysis can be successfully applied for the elimination of organic matter in these solutions.

Notes on the Efficient Working of Gas-Producer Plant. (Fuel Economy Review, 1941, vol. 20, pp. 27–38). The efficient operation of gas producers is recognised to be an important item in industrial practice, and this paper is intended to afford practical guidance on the operation and management of gas-producer installations. Information is presented on such items as: (a) The fundamental basis and the mechanism of efficient gasification; (b) the function of steam in the blast; (c) the detection of inefficient operation; (d) fuel selection; (e) feeding, poking, clinkering and ash removal; (f) controlling the blast saturation temperature and the gas pressure; (g) measuring the exit temperature; (h) metering the coal, air, gas and steam; and (i) checking the quality of the gas.

Purification of Air and Gases. (Iron and Coal Trades Review, 1941, vol. 143, Oct. 10, p. 339). Particulars are given of recent improvements in the design of the Traughber froth-flotation filter for gases. (See Journ. I. and S.I., 1941, No. II., p. 159 A).

PRODUCTION OF IRON

Desulphurisation of Basic-Bessemer Iron. W. Eichholz and G. Behrendt. (Iron and Coal Trades Review, 1941, vol. 143, Oct. 17, pp. 356–357). An abridged English translation is presented of the

authors' paper on German developments in the desulphurisation of pig-iron. The original paper appeared in Stahl und Eisen, 1940, vol. 60, Aug. 1, pp. 677–683 (see Journ. I. and S.I., 1941, No. II., p. 69 A).

The Technology of Slags as a Basis for the Metallurgy of Iron **Production.** F. Körber and W. Oelsen. (Stahl und Eisen, 1940. vol. 60, Oct. 17, pp. 921–929; Oct. 24, pp. 948–955). The authors discuss some fundamental data relating to slags and apply their conclusions to the metallurgy of iron production. In the first part the use of slag constitutional diagrams for studying the viscosity of slag (especially basic slag) is explained with particular reference to the effect of equilibrium and non-equilibrium conditions. The meaning of the curves for the commencement of solidification in binary systems and of the corresponding saturation surfaces in isothermal sections of ternary systems are discussed. The characteristics of the behaviour of silica, phosphorus pentoxide, alumina, ferrous oxide, fluorspar and magnesia in slags and the conditions promoting the formation of a highly basic slag are pointed out. As one of the salient facts it was established that, with regard to the metallurgical effect of basic slags, the question of which compounds (pure lime, lime silicates or lime phosphates) they are to be saturated with at the temperatures normally attained and with given proportions of fluxes (FeO, Al₂O₃, CaF₂) is critically important. Other facts which were established included: (a) The close association which exists between the silica and iron contents of openhearth slags; and (b) the sum of the contents of CaO, MgO and MnO (expressed in percentages) can vary only very slightly. When making steel with a basic slag, the saturation limits of the lime and its high-melting-point compounds are just as important factors as is the solubility of the silica in the silicate slags of the acid process. The effect of fluorspar was established by experiments. In the liquid state they are practically immiscible, so that a fluorspar addition to highly basic slags has two distinct effects: it thins out the viscous slag, thus making it physically more capable of reaction, and it makes the iron oxides in the slag chemically more capable of reaction. A schematically developed FeO-V₂O₃ constitutional diagram is used to explain the peculiarities of vanadium slags. The high melting points of the compounds V₂O₃ and FeO. V₂O₃, and their consequent low solubility in other slags, afford an explanation of the fact that more vanadium passes into the slag from a vanadium-bearing iron refined in the Bessemer converter than when it is treated with ore in the open-hearth. The CaO-Fe₂O₃ constitutional diagram, together with information from the literature, is used to prove that lime ferrite in molten slags in contact with iron at high temperatures can have little stability. Attention is drawn to the important factors affecting heat-balance calculations for iron smelting processes, with particular reference to the proportion of the total heat that is necessary for the formation of fluid slags.

Hot-Pressing of Iron Powders. P. Schwarzkopf and C. G. Goetzel. (Iron Age, 1941, vol. 148, Sept. 4, pp. 37–44). The authors review the knowledge and experience gained in the production of parts by the hot-pressing of iron powders, and present tables and graphs showing the tensile and hardness properties of products made by pressing iron powders made from electrolytic iron, Swedish sponge iron and hydrogen-reduced iron at various temperatures. The beneficial effect of a short-time annealing treatment after pressing is pointed out.

FOUNDRY PRACTICE

Why Sulphur Pick-Up Varies in Cupola Iron. R. A. Clark (Foundry, 1941, vol. 69, Sept., pp. 54–55, 140). The author describes his experience at an American foundry where he endeavou red to establish the cause of the increase in the percentage of sulphur in the cupola iron. The evidence obtained pointed to the conclusion that although different cokes may contain the same amount of sulphur, the proportions of sulphur retained in the coke ash and of volatile sulphur may vary considerably. It is therefore probable that the increase of sulphur in the iron was due to using a coke with a high proportion of volatile sulphur.

Melting in the Cupola. S. C. Massari and R. W. Lindsay. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Sept., pp. 94–115). The authors review several articles on cupola practice, mainly by Jungbluth, Heller and Korschan, which have appeared in the German technical press during the last seven

years.

Construction and Operation of a 15-Inch Cupola. F. Holtby. (Foundry, 1941, vol. 69, Aug., pp. 66-67, 114-116). The author describes the construction and operation of a small cupola which has been installed for instructional and research purposes at the Minnesota University. The cupola is 24 in. in outside dia., 15 in. in inside dia. and 8 ft. 4 in. high. It is made in two parts, the joint being just above the melting zone. The upper part is removable to facilitate patching. The lower part carries the wind-belt and four 3½-in. tuyeres. There are four sets of short flanged pipes which connect the tuyere sto the wind-belt; each set is of different length, so that the tuyere height can be adjusted to suit the quantity of iron it is desired to melt. Details of the charging and tapping practice are given. The cupola has worked very well for a year, and close control of the carbon, silicon and manganese contents of the iron was possible.

Some Observations in the Duplexing of Malleable Iron. G. A. Schumacher. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Sept., pp. 123–128). The author discusses

slag practice in the preparation of malleable iron by the duplex cupola/air-furnace process. He gives a time-table of the actual procedure for the dilution of the iron-oxide in the slag in the air furnace by additions of limestone and silica sand to the bath. It is stated that this practice facilitates the control of the carbon, silicon and manganese and reduces the consumption of refractory bricks at the furnace bottom.

Some Fundamental Aspects of Foundry Sand. E. J. Ash and E. O. Lissell. (Foundry, 1941, vol. 69, July, pp. 60–61, 118, 119; Aug., pp. 60, 130–131). The authors refer to the differences in the methods of preparing specimens of moulding sand with which to make tests in accordance with British and American standard specifications. In the first part the results of tests are presented which show the effect of moisture on the permeability and density of a round-grained Ottawa sand and an Ohio crushed silica sand with angular grains. It was observed that increasing the quantity of moisture above about 1.25% steadily increased the density of round sand, whilst that of angular sand remained constant. In the second part the effect of moisture on the internal friction and flowability of clay-free sands is discussed. It is shown that with increasing moisture up to about 2% the friction increases and the flowability decreases. Additions above 2%, however, cause no further increase in friction or decrease in flowability. The critical moisture content is slightly higher for a fine-grained sand.

American Synthetic Sand Practice. N. J. Dunbeck. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Sept., pp. 141–164). The author describes current American foundry practice in the preparation of synthetic moulding sands. (See

Journ. I. and S.I., 1941, No. II., p. 114 A).

Co-operation of the Engineer, Pattern-Maker and Foundryman. E. J. Brady. (American Foundrymen's Association: Foundry Trade Journal, 1941, vol. 65, Sept. 25, pp. 201–203). The author makes a number of practical suggestions for the use of pattern-makers and moulders. These related to pattern draft (the degree of taper on a pattern to facilitate its withdrawal), shrinkage allowances, gates and risers, core-making and core-prints, core-boxes for blowing machines, chaplets and the properties of pattern-making materials.

Permanent Mould Castings. (Iron Age, 1941, vol. 148, Sept. 4, p. 62). A brief description is given of the Wagner machine for the casting of sewer manhole rings 2 ft. 6 in. in dia. weighing 160 lb. No cope is required. The drag and the core section are made of semisteel; the former is fixed, and the latter can be raised into the casting position by a hydraulic ram. Both parts of the mould are heated to about 300° F. before casting, and they are coated with a refractory material after each cast. Risers are not used. Provision is made for passing a controlled amount of cooling oil through both the drag and the core to keep the mould at an even temperature. Rings can be cast at the rate one every 15 min. with this machine.

Centrifugal Casting and Equipment. N. Janco. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Sept., pp. 193–201). The author describes the equipment and procedure for vertical centrifugal easting, pointing out the advantages and limitations of the process and giving some details of the saving in cost as compared with static moulds when large numbers of castings

are required.

An Efficient Materials Handling System for Cleaning Castings. (Steel, 1941, vol. 109, July 28, pp. 58–60). A brief description is given of a conveyor system installed at an American foundry producing malleable iron pipe fittings. After the fittings leave the heat-treatment furnace they are dumped on a vibrating shake-out screen, from which they pass up an inclined conveyor to a hopper, which feeds two shot-blast cleaning machines. From these machines the castings pass by another conveyor on to a ring conveyor, within which stand inspectors and sorters, who pass the castings and load

them into barrels conveniently placed outside of the ring.

The Fluidity of Ingot Iron and Carbon and Alloy Cast Steels. H. F. Taylor, E. A. Rominski and C. W. Briggs. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Sept., pp. 1-83). The authors have studied the fluidity of cast steel as measured by various types of test-pieces, including the spiral fluidity test which was found to give the most accurate and dependable results. The experimental technique, designed for as complete a control of the variables as possible, is described in detail. A testing procedure is outlined whereby it is possible to use the spiral fluidity test effectively at the furnace for determining proper tapping times. The material of which the test mould is made (i.e., whether of cement-sand, green sand or dry sand) had no effect on the fluidity of the cast steel as measured by the spiral. The length of the spiral when cast in naturally bonded green sand moulds was consistently longer than when cast in naturally bonded dry sand moulds. The use of a mould-wash decreased the length of the spiral slightly, but gave better reproduction of the mould cavity. Temperature was found to be a very important factor in governing the flowing power of steel. The carbon content was found to affect the fluidity to a small degree only. With regard to deoxidation practice, it was found that it was necessary to have a certain critical amount of oxide present to obtain maximum fluidity. Under the experimental conditions described, the addition of the alloying elements molybdenum, vanadium and chromium slightly decreased the fluidity of the steel, whilst copper and nickel increased it. It was found essential to maintain the silicon above a critical value, or to supplement it by a suitable deoxidiser, in the interests of fluidity and soundness. Manganese, in the amounts usually employed in carbon steels, did not increase the fluidity at normal pouring temperatures. When present in higher concentrations, manganese markedly increased the fluidity at lower temperatures.

PRODUCTION OF STEEL

Empire Iron and Steel Developments. (Iron and Coal Trades Review, 1941, vol. 143, Sept. 26, pp. 290–292). A review of the war-time expansion of iron and steel works in the countries of the British Empire is presented. A survey of actual output statistics on the basis of plants built or building suggests that Canada, India, Australia and South Africa will soon be producing about 6,000,000 tons of pig iron and 6,500,000 tons of steel per annum. This compares with a combined output in 1937, the record year before the present war, of 3,800,000 tons of pig iron and 3,600,000 tons of steel.

Analysis of the Generation and Delivery of the Blast to the Metal in a Bessemer Converter. J. S. Fulton. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1344: Metals Technology, 1941, vol. 8, Sept.). The author studies factors which affect the blast supply to Bessemer converters with a view to improving the economy of the Bessemer process. He makes the following recommendations: (1) The air circuit should be streamlined and leaky joints repaired; (2) the blast-pipes should be insulated; (3) hot-blast stoves or heat exchangers should be installed to increase the blast temperature at the wind box; (4) the humidity of the blast should be maintained at a uniform level; (5) every converter should be calibrated to determine the combination of wind pressure and size and number of tuyeres which will give the optimum combination of blowing cost and lining life; (6) the operator should be provided with visible indications of the amount of wind entering the riser pipe and, if possible, the air pressure in the wind box; and (7) the operator should be provided with a comfortable pulpit from which to control the blowing operation.

The Technical Importance and Economy of Blast-Drying in Basic-Bessemer Works. W. Eilender and P. Veit. (Stahl und Eisen, 1940, vol. 60, Oct. 10, pp. 905–910). The authors first consider the physical and chemical nature of the reactions between the moisture of the blast and the molten metal when a Bessemer converter is being blown, and show that 80% of this moisture is decomposed. Improved methods of analysis have enabled the amount of hydrogen absorbed by the steel to be determined; this amount varies with the moisture content of the air, and is between 5 and 20 c.c. (at N.T.P.) per 100 g. of steel. The detrimental effect of hydrogen on the steel is pointed out. They then describe plants for removing moisture from the blast by refrigeration and with silica gel, and compare the costs of these processes, showing that the latter is the better both technically and economically. It is shown that moisture in lime has practically no effect on the steel. In conclusion the economic advantages of reducing the

phosphorus content of the blast-furnace charge under German smelting conditions is discussed.

A Study of Modern Bessemer Steels. E. E. McGinley and L. D. Woodworth. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1346: Metals Technology, 1941, vol. 8, Sept.). The authors review the physical characteristics of Bessemer steels, comparing them with those of open-hearth steels, and discuss methods of controlling the Bessemer process. Curves are presented which show the relation between the teeming temperature of acid Bessemer steel and the cost of conditioning billets made from it; these indicate that there are optimum teeming temperature ranges of about 2880–2900° F. for killed steel and about 2850–2870° F. for rimming steel. Curves are also presented which show the rapid increase in the formation of iron oxide as the carbon decreases during the blow and the effect of the teeming temperature

on the nitrogen content of the finished steel.

"Chrom-X" and Our Chromium Problem. M. J. Udy. (Metals and Alloys, 1941, vol. 14, July, pp. 52-55). The use of Chrom-X for introducing chromium into alloy steels was discussed at the Twenty-fourth Open-Hearth Conference (see Journ. I. and S.I., 1941, No. II., p. 197 A). In the present paper some information on the preparation of high-carbon and low-carbon Chrom-X briquettes is given. To produce this material a direct reduction of the ore or concentrate is made in an electric furnace with coke to produce a chromium-iron metal with 8-10% of carbon and up to 5% of silicon. The high-carbon quality is made up of this metal mixed with sodium nitrate or another oxidising agent, such as sodium or calcium chromate, in sufficient quantity to oxidise practically all of the silicon and part of the carbon. It is then briquetted and heated to bond it into a solid mass. The oxidising agent forms the bond. As the materials are finely ground and thoroughly mixed, the product is of uniform composition.

Electric-Arc-Furnace Oxidation Practice. N. F. Dufty. (Metallurgia, 1941, vol. 24, Sept., pp. 131-133). The author reviews the literature on the effects, sources and elimination of hydrogen, nitrogen, sulphur, phosphorus and non-metallic inclusions in steel and makes suggestions regarding basic electric-furnace practice with a view to preventing the detrimental effects referred to in the review. The advantages of charging limestone instead of burnt lime and of having a vigorous boil are pointed out. If high-carbon scrap is used, ore can be charged to start a reaction before the scrap in front of the door has melted. If the scrap is light and rusty, carbon must be added in the charge. A fairly high amount of residual manganese helps the boil to eliminate slag inclusions formed by the oxidation of silicon in the scrap, and the low temperatures at this stage favour the removal of sulphur from the metal into the slag by the formation of manganese sulphide. When the metal is hot enough to take it, ore is fed in sufficient quantity, accompanied by

lime (not limestone at this stage), to prevent the formation of a thin oxidising slag which attacks the banks and removes neither

sulphur nor phosphorus.

The Life of Ingot Moulds. K. Knehans and N. Berndt. (Stahl und Eisen, 1940, vol. 60, Oct. 31, pp. 973–977). The authors review the literature on the factors which affect the life of ingot moulds.

The Ladle Cooling of Liquid Steel. T. Land. (Journal of the Iron and Steel Institute, 1941, No. II., pp. 157 P-168 P). It is now possible to control and measure with accuracy the temperature of liquid steel in the melting furnace, and thus it has become important to know what fall in temperature is to be expected between tapping and casting. The present paper explains how this may be calculated. A simple experiment with a model shows how the metal in the ladle cools by a relatively thin layer of metal passing down the vertical walls of the refractory lining and forming a reservoir of cool metal at the bottom of the ladle. The amount of heat extracted by the ladle refractories is calculated, and particular attention is drawn to the effect of preheating the ladle. It is deduced that, to obtain efficient preheating, the preheating period must bear a definite relation to the time taken to tap and cast. The results of the investigation are presented in the form of a Table which gives the drop in temperature for different sizes of ladle and different times of casting and tapping. It is shown that the effect of varying the tapping temperature and the temperature to which the ladle is preheated can be allowed for by multiplying the figures in the Table by a simple factor. A second Table gives corrections which may be applied for different methods of casting and for the time that the metal is held in the ladle between tapping and casting. The theory goes far to explain certain unexpected results in observed casting temperatures.

The conditions for obtaining a uniform casting temperature are outlined. An Appendix summarises the mathematical approach to

the problem.

Diesel Switching Equipment for Steel Plants. E. M. Smith. (Iron and Steel Engineer, 1941, vol. 18, July, pp. 59–63). The author discusses the advantages of Diesel-electric locomotives for shunting as compared with steam locomotives. Statistics are presented showing that there has been a remarkable increase in the last three years in the use of Diesel locomotives in the United States. The author claims advantages in general efficiency, safety, track economy, fuel economy and maintenance for the Diesel engine, and stresses its usefulness for steelworks shunting. General data for 300, 600 and 1000 h.p. Diesel locomotives are given.

The Design of Crane Parts on the Basis of Accident Experience. K. Schwantke. (Stahl und Eisen, 1940, vol. 60, Oct. 17, pp. 930–932). From his experience in the investigation of the causes of accidents with steelworks cranes in Germany, the author makes

recommendations on safety measures in crane designs with special reference to electric cranes. Some difficulties resulting from black-out regulations are also dealt with.

REHEATING FURNACES

Comparison of Soaking Pit Designs. F. E. Leahy. (Iron and Steel Engineer, 1941, vol. 18, Aug., pp. 64–71). The author reviews the various types of soaking pits now available. The features which have become standardised and are common to modern installations include the lifting type of cover with a sand-seal and the automatic control of temperature, pressure and combustion. The greatest variation is to be found in the methods of supplying the heat. The Chapman-Stein, the Amsler-Morton and the Salem soaking-pits are briefly described, and a chart is reproduced which shows how the soaking-pit fuel consumption varied with the production of ingots over twelve months at a large American steelworks.

Experience in the Design and Operation of a Pusher-Type Slab Furnace Fired with Blast-Furnace Gas. F. Domes and H. Schwenke. (Stahl und Eisen, 1940, vol. 60, Dec. 19, pp. 1152–1156). The authors describe a large reheating furnace recently constructed at a German plate-mill. The hearth is 20 m. long × 3·2 m. wide. It is heated with blast-furnace gas through five burners at one end and three burners on each side, and the gas and air are preheated by steel recuperators. The slabs are pushed through the furnace in two rows on two sets of water-cooled skid rails and are heated up to 1350° C. The heating capacity of the furnace is 20 tons per hr., with a heat consumption of 435,000 kg.-cal. per ton. The furnace has fulfilled the design expectations in all respects. Diagrams of the furnace and of the burner detail are presented and the method of control is described.

Reheating Furnaces for Steel Plants. W. Trinks. (Industrial Heating, 1941, vol. 8, May, pp. 504-508, 512). A review of various types of soaking pits and reheating furnaces is presented, the author basing his information on an article by T. Stassinet which appeared in Stahl und Eisen, 1940, vol. 60, Sept. 12, pp. 809-815 (see Journ. I. and S.I., 1941, No. II., p. 75 A).

FORGING, STAMPING AND DRAWING

Forging Guns at Titusville. A. F. Macconochie. (Steel, 1941, vol. 109, Aug. 25, pp. 54–60, 82). The author presents an illustrated description of the forging and machining operations in the manufacture of gun-barrels of 37-mm. bore and larger at the works of the Struthers Wells-Titusville Corporation in Pennsylvania.

20,000 Shells a Day by General Motors. F. J. Oliver. (Iron Age, 1941, vol. 148, Aug. 7, pp. 41–44; Aug. 14, pp. 46–51). The author gives an illustrated description of the forging and machining operations at the General Motors Corporation, Lansing, Michigan, where 75- and 105-mm.-dia. shells can be produced at the speed of 20,000 in 24 hr. The conveying equipment has been highly mechanised and the "line" system of production has been applied to reduce manual labour to a minimum. The forgings are heated by high-frequency induction furnaces and are pierced by the upset method in five operations (see Journ. I. and S.I., 1941, No. I., p. 158 A). The finish-turning of the forgings is done by a battery of four automatic vertical lathes, each of which has eight spindles

rotating about a centre column.

Die-Typing to Speed Production. W. F. Sherman. (Iron Age, 1941, vol. 148, July 31, pp. 35-37, 96; Aug. 7, pp. 46-51). The author describes a process of making series of exactly similar dies which has been developed by the Ford Motor Co. This process is known as "die-typing," and has proved economical when more than about ten sets of duplicate dies are ordered at a time. For the mass production of symmetrical bodies by die-forging, a "mastermaster" die has first to be made by machining in the usual way; this die represents an impression to half depth of the part to be manufactured. This master-master die is mounted on a retaining block on the ram of a powerful press, and it is then used to hotforge the required number of "master" dies in suitable blocks of die steel held in retaining blocks mounted on the anvil of the press. Pairs of the master blocks thus produced are used for the mass production of the part required. Information is also given on the advantages and limitations of the process, shrinkage allowances, trimming and hardening the dies, timing of pressing operations and the life of dies.

Dies—Their Design, Scheduling and Production. J. Mueller. (Heat Treating and Forging, 1941, vol. 27, July, pp. 323–325). A brief account is given of the method employed at an American forging works for dealing with orders for dies. The system of allocating work to different departments and individual machines

is explained and specimens of the forms used are reproduced.

Hot Die Steels for Forging Shell. W. H. Wills. (Steel, 1941, vol. 109, Sept. 1, p. 62). The author gives some information on suitable steels for the mandrels used in the shell-piercing machines referred to in a paper entitled "Shaping Steel to Form High-Explosive Shell" (see Journ. I. and S.I., 1941, No. I., p. 210 A). For the first piercing operation a die steel containing carbon 0·30%, tungsten 9%, chromium 3% and vanadium 0·50% is recommended. A 1·25%-silicon, 5%-chromium steel is recommended for the sub-mandrel supporting the point used in the second "sizing" operation. The heat treatment for these two steels is given.

The Forging of Tool Steel. I. Stewart. (Iron and Steel, 1941, vol. 14, Sept., pp. 451–454). The author makes recommendations on the reheating and forging of various types of tool steel ingots. There is still some controversy on the advantages of tools forged down from the ingot as compared with those forged from rolled

bars. The author prefers the tools made by forging only.

The Engineer in the Drop Forging Industry. A. Russell. (Journal of the Junior Institution of Engineers, 1941, vol. 52, Oct., pp. 15–25). The author describes the organisation of a drop-forging shop, treating the subject under the following headings: (1) Raw material stores; (2) forging department; (3) heat treatment; (4) inspection and despatch; and (5) die-sinking and tool-making departments. Some forging presses and small reheating furnaces are described and some recommendations on the use of pitch-creosote mixtures—a fuel produced in Britain—for these furnaces are made. This fuel should be kept at 80° F. in the storage tanks, and the pipe-lines must be heated and insulated, and be capable of circulating the mixture at a pressure of 50 lb. per sq. in. The mixture must be heated to 200° F. at the burners.

Mild Steels for Stamping in Soft Metal Dies. E. C. Rollason. (Sheet Metal Industries, 1941, vol. 51, Sept., pp. 1151–1155, 1165; Oct., pp. 1283–1286). The author discusses the characteristics of mild-steel sheet suitable for making stampings in soft metal dies. Defects in sheet traceable to composition and to the various stages of manufacture, the influence of the direction of rolling, the cause of stretcher-strain markings and the factors affecting recrystallisation after heat treatment and strain-ageing are dealt with in turn. Some continuous annealing furnaces for small stampings are de-

scribed and illustrated.

Power Requirements for Hot-Pressing. A Eichinger and A. Pomp. (Archiv für das Eisenhüttenwesen, 1940, vol. 14, July, pp. 1-6). The authors explain their method of calculating the power requirements for hot-pressing with and without the metal rising in the die, and give some examples of its practical application.

Cost Calculations and Price Fixing for Drawn Wire. K. Schwantag and H. Linke. (Archiv für das Eisenhüttenwesen, 1940, vol.

14, Sept., pp. 133-143).

ROLLING-MILL PRACTICE

Step-by-Step Procedure for Grinding Ultra-Finish Rolls. H. J. Wills. (Steel, 1941, vol. 109, July 28, pp. 78–80, 88). In this, the third article of his series on the production of a highly polished surface in steel rolls (see Journ. I. and S.I., 1941, No. II., p. 201 A), the author describes the exact sequence of grinding operations, giving for each step details of the grinding-wheel grit size, surface

speed, traverse rate and type of dressing. The method of grinding

tungsten-carbide rolls for Steckel mills is also given.

Application and Care of Bearings in Steel Plant Auxiliaries. F. L. Gray. (Iron and Steel Engineer, 1941, vol. 18, Aug., pp. 50-55). The author discusses problems connected with the lubrication of the journals of slag-tipping bogies, auxiliary rolling-mill

machinery and large gas engines.

An Exhibition of Proved Substitute Materials. E. Rohde. (Stahl und Eisen, 1940, vol. 60, Nov. 7, pp. 997–1001). In order to spread information regarding home-produced substitutes for expensive imported materials and to encourage the use of the former in Germany, a travelling exhibition of many parts made of substitute materials which have proved their value has been organised. In the present paper the author describes several of the exhibits which have applications in the iron and steel industry. These include synthetic resin bearings for rolling-mill stands, roll-trains, craneshafts and pumps; synthetic resin worm-wheels and pump impellers; sections of steel rail used as live conductors for travelling cranes instead of copper cables; and bearing metals high in lead and low in tin.

Lubrication in Its Relation to Maintenance. C. W. Phillips and R. A. Barta. (Iron and Steel Engineer, 1941, vol. 18, July, pp. 64–70). The authors explain some of the duties of a lubrication engineer at a steelworks. They point out some important factors in the design of lubrication for new machines which will affect the future maintenance, and give examples of lubrication instruction sheets for various departments of a steelworks.

Observations on Design and Operation of Rod Mills. L. Moses. (Iron and Steel Engineer, 1941, vol. 18, Aug., pp. 30-35). The author describes the changes and improvements in the layout in the rod mills at the works of the Bethlehem Steel Co., with particular reference to the arrangement of mill-stands and the pass

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Brief History of the Plate Mill. A. W. Soderberg. (United Effort, 1941, vol. 21, Aug., pp. 9–12, 14). The author presents a brief history of the development of plate mills in the United

States.

The Experimental Rolling of Sheet from Large Stainless Steel Ingots. D. Gurevich and S. Belorusov. (Iron and Steel, 1941, vol. 14, Sept., pp. 431–432, 437). An English translation is presented of the authors' paper on the results of rolling tests on two 10-ton ingots of stainless steel. This appeared originally in Stal, 1939, No. 10–11, pp. 49–52. (See Journ. I. and S.I., 1941, No. I., p. 52 A).

The Effect of Forward Tension and Backward Tension on the Cold-Rolling Process. W. Lueg and F. Schultze. (Stahl und Eisen, 1940, vol. 60, Dec. 26, pp. 1173–1180). An abridged report of the authors' investigation of the effects of different degrees of forward

and backward tension on the cold-rolling of steel strip is presented. The full report appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 7, pp. 93–108 (see

Journ. I. and S.I., 1941, No. II.; p. 173 A).

Producing Continuous Butt-Welded Pipe. L. J. Hess. (Metals and Alloys, 1941, vol. 14, July, pp. 31–36). The Bethlehem Steel Co. has recently installed a second mill for the continuous production of steel tubes by the Fretz-Moon process. This mill is similar to the first one (see Journ. I. and S.I., 1940, No. II., p. 146 A). In the present description more attention is paid to the heating furnace in which the preheating zone is much shorter than that of No. 1 furnace (29 ft. 6 in. and 16 ft. respectively), whilst the three heating zones are all somewhat longer; the overall lengths are 146 ft. and 155 ft., respectively. In No. 2 furnace, skelp for 1½-in. and 4-in.-dia. tubing passes at speeds of 238 ft. and 95 ft. per min., respectively.

Floating Motor-Drives for Roller Tables. A. M. MacCutcheon. (Iron and Steel Engineer, 1941, vol. 18, Aug., pp. 24-29). The author describes and illustrates a new type of floating drive and bearing for the rolls of roll-trains which are driven by individual motors. This has been described in a previous article (see Journ.

I. and S.I., 1941, No. II., p. 202 A).

Regulating Devices. C. R. Hanna and R. H. Wright. (Iron and Steel Engineer, 1941, vol. 18, July, pp. 29–38). The authors review the progress made in the design of electrical regulating equipment, and describe and illustrate several types of regulators which have particular applications in steelworks.

PYROMETRY

Notes on Pyrometric Cone Equivalent Determinations. E. C. Petrie. (Bulletin of the American Ceramic Society, 1941, vol. 20, Sept., pp. 299–302). The author discusses the preparation of Seger cones and some factors which affect the accuracy of the results obtained when determining the softening point of refractory materials by means of Seger cones. The importance of selecting suitable material for making the plaque, or base on which the cones stands, is stressed because the lower-melting-point constituents of the cones may migrate into the plaque or vice versa. The use of organic binders in making the test cones may cause bloating of the surface when they are heated, thus preventing them from collapsing in the normal manner. Starch paste should not be used as a binder when making up cones as this causes bloating.

Measurement of Liquid Steel Temperatures by the Schofield-Grace Method. T. Land. (Metal Treatment, 1941, vol. 7, Autumn Issue, pp. 107-110, 113). The author describes the method of

measuring liquid steel temperatures developed by Schofield and Grace (see Eighth Report on the Heterogeneity of Steel Ingots, I. and S.I. Special Report No. 25, p. 239), some of the millivoltmeters available for measuring the current from the thermocouple, and some of the improved equipment which has been developed for

taking temperatures in different types of steel furnaces.

The Measurement of Flame Gas Temperatures. W. T. David. (Engineer, 1941, vol. 172, Sept. 19, pp. 186–187). The author discusses the accuracy of the measurement of flame temperatures by the sodium line reversal method and by that in which thin insulated or uninsulated platinum wires are immersed in the flame. He is of the opinion that the sodium method is fundamentally unsound, mainly because air-gas mixtures are never perfectly mixed in practice. Curves are presented showing the temperatures attained by the wire method when mixtures of carbon monoxide and air were exploded in a closed vessel. When these were compared with the calculated ideal curve, it was seen that the temperatures obtained using quartz insulated wire were approximately correct, whilst the curves for uncovered wires differ considerably from the other two.

The Selection of Pyrometer Equipment. A. J. T. Eyles. (Mechanical World and Engineering Record, 1941, vol. 110, Sept. 19, pp. 189–190). The author gives the approximate temperature ranges for which electrical resistance, thermocouple, radiation, optical and photo-electric pyrometers can be used, and briefly discusses factors which influence the accuracy of the readings obtained with them

under industrial conditions.

HEAT TREATMENT

Laminated Springs. (Automobile Engineer, 1941, vol. 31, Sept., pp. 295–298). A detailed and illustrated description is given of the heat treatment, pressing and grinding operations at an English works manufacturing laminated springs for motor-cars. A high degree of mechanisation has been adopted, which has resulted not only in an increase in the output, but also in an improvement in the quality and uniformity of the springs.

Heat Treatment of Molybdenum High-Speed Steels. (Steel, 1941, vol. 109, Sept. 8, pp. 60-61, 73). A number of heat-treatment schedules for molybdenum high-speed steels of the following com-

position are presented:

		(a)	(b)	(c)
Carbon % .		0.70-0.85	0.70-0.90	0.75-0.90
Tungsten %		1.25 - 2.30		5.00-6.00
Chromium %		3.00 - 5.00	3.00-5.00	3.50-5.00
Vanadium %		0.90 - 1.50	1.50-2.25	1.25 - 1.75
Molybdenum %		8.00-9.50	7.50 - 9.50	3.50-5.50

These steels may also contain up to 9% of cobalt, but if steel of type (c) contains cobalt it becomes susceptible to decarburisation.

Precipitation Hardening Effects in "Plain" Ferritic Steels. H. W. Gillett. (Metals and Alloys, 1941, vol. 14, Aug., pp. 161-The author reviews the literature on the precipitation hardening of steel with special reference to the work of Houdrement, Bennek and Wentrup, and of Epstein. From the evidence cited the present author is of the opinion that the occurrence of intergranular corrosion is indicative of an accumulation of precipitate at the grain boundaries. The less thoroughly deoxidised a steel is, and the smaller the amount of the aluminium addition, the more readily does the precipitate accumulate at the grain boundaries. Neither a mere content of excess metallic aluminium nor mere fine grain suffices to prevent the solution and precipitation phenomena. Steel can be very susceptible to intergranular corrosion notwithstanding a fine grain, and it appears as though not only the amount of aluminium added, but also the condition of oxidation of the melt at the time it is added, have an important effect on the susceptibility of steel to intergranular corrosion.

Case Hardening à la Carte. (Iron Age, 1941, vol. 148, Sept. 11, pp. 45-47). The author describes the heat-treating equipment of an American company manufacturing chucks; this includes electric furnaces for pack carburising and a gas-fired nitriding furnace. The latter furnace has a reciprocating muffle suspended inside the furnace shell. A motor-driven cam retracts the muffle against spring pressure, which rapidly propels the muffle forward when the cam drops. The forward movement is suddenly stopped by a buffer on the muffle striking a stop, and the work is thus moved

forward step by step by its own momentum.

Salt-Bath Method for Hardening Molybdenum High-Speed Steels. (Steel, 1941, vol. 109, Sept. 8, pp. 73–76). The use of molybdenum high-speed steel in place of the high-tungsten steel has led to increased interest in the methods of hardening molybdenum steels. In this article recommendations are made regarding the selection of equipment and the procedure for hardening these steels in salt

baths heated by immersed electrodes or by gas or oil.

Some Aspects of Gas Carburising. I. Stewart. (Metal Treatment, 1941, vol. 7, Autumn Issue, pp. 87–91). The author gives an account of the development of the gas-carburising process, referring particularly to the pioneer work of Giolitti and Machelet, and explains the theory of the process as now practised. The special properties of some city gases, methane, butane and propane, are compared and their particular functions in gas mixtures for carburising are pointed out.

Flame-Hardening Malleable Iron. S. Smith. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Sept., pp. 209–222). The author describes two procedures for flame-hardening blackheart and pearlitic malleable cast irons. The oxy-acetylene

flame is used in both cases. In the first, the whole surface is heated and then quenched in one immersion. The second is a progressive method in which the flame and the quenching jet both traverse the surface to be hardened. The correct time-temperature relationships to obtain either martensitic or cementitic structures are given, and the influence of design on the suitability of a casting for flame-hardening is discussed.

The Shorter Process. (Automobile Engineer, 1941, vol. 31, Sept., pp. 303–306). Particulars are given of the degree and depth of hardness obtained by applying the Shorter flame-hardening process to a number of alloy steels. Three Shorter hardening machines for the repetition hardening of camshafts, flat surfaces, such as caterpillar track-shoes, and small repetition work are

described.

Developments in Continuous Annealing of Steel Strip. J. D. Keller. (Mechanical Engineering, 1941, vol. 63, July, pp. 507–513). After pointing out some of the difficulties to be met in designing a continuous annealing furnace for steel strip, the author describes a vertical gas-fired experimental unit at an American steelworks. The furnace is intended for annealing strip 0·0086–0·025 in. thick, up to 38 in. wide, at speeds of 75 to 300 ft. per min. The furnace is about 30 ft. high, it has two heating passes and six cooling passes, and it operates at about 1700° F. The strip is heated by horizontal gas-fired radiant tubes on both sides of the strip. The mechanical equipment is described in detail and information is also given on the cleaning and temper-rolling processes, the properties of the

strip produced and the costs.

Improvements in the Bright-Annealing of Low-Carbon Steel Sheets. F. Eisenstecken and E. Schauff. (Stahl und Eisen, 1940, vol. 60, Oct. 31, pp. 968–973; Nov. 7, pp. 1001–1005). The authors report on an investigation by two important German steelworks of the factors affecting the bright-annealing of deep-drawing-quality low-carbon (0.09%) steel sheets using (a) unburnt coke-oven gas free from sulphuretted hydrogen, and (b) the products of the partial combustion of coke-oven gas. The following conclusions were arrived at regarding the use of unburnt coke-oven gas: (1) If the annealing temperature is kept below 570° C., it is scarcely possible for the cracking of methane with the deposition of carbon to take place, neither will carbon monoxide have any effect on the surface of the steel at this temperature. (2) The removal of small quantities of oxygen which may be present will prevent oxidation at the edges of the sheet, discoloration and a matt appearance of the surface of the sheet; the oxygen can be removed by passing the gas over copper held at 280–400° C. (3) Any steam in the gas must be removed. (4) Efforts should be made to remove any organic sulphur compounds which may be present.

The successful bright-annealing at about 600° C. in an atmosphere of partially burnt coke-oven gas with a low gas consumption

requires that: (1) The gas and air must be thoroughly mixed before entering the combustion chamber and good turbulence must be maintained in the combustion chamber itself. (2) To prevent any deposition of carbon the amount of unburnt methane must be kept as low as possible (under 1%); this can be done by keeping the gas/air ratio between 1:2.5 and 1:3. (3) The sheets must not be allowed to rust before annealing, as in that case the reducing action of the hydrogen may be inhibited. (4) Any small quantities of oxygen present in the protective atmosphere must be removed before it enters the annealing chamber. (5) The amounts of carbon monoxide, carbon dioxide, steam and hydrogen in the protective atmosphere must be such that the equilibrium constants do not reach or exceed their permissible values for the annealing temperature. (6) If the $p \stackrel{\circ}{CO}_2/p \stackrel{\circ}{CO}$ ratio is between 0.2 and 0.6for a given gas/air ratio, it is not necessary to take special measures to remove the carbon dioxide. (7) The moisture content of the gas must be kept as low as possible so that the steam/hydrogen ratio is less than 0.1.

New Type of Circular Bell Furnace Used for Annealing Wire and Strips. (Industrial Heating, 1941, vol. 8, Apr., pp. 390–393). An illustrated description is given of an improved type of cylindrical furnace for annealing coils of wire and strip. This installation consists of three bases, one heat-retaining cover and one furnace. The lower part of the furnace is made of steel with a refractory lining to which is welded an alloy-steel hood. The furnace is heated by a number of Π -shaped radiant tubes, the firing ends of which are welded into the steel casing. For the greater part of their length these tubes are within the alloy steel hood, and the latter retains the heat radiated from the former. The exit ends of the tubes are welded to the hood so that no products of combustion can enter

the annealing chamber.

Determination of Spheroidizing Cycles in New Annealing Department. H. L. Hopkins. (Wire and Wire Products, 1941, vol. 16, Aug., pp. 437-440, 471). The author describes an investigation to determine the optimum annealing temperature and holding time for coils of $\frac{11}{32}$ -in.-dia., 0.35% carbon steel rod for making bolts and studs by cold-heading. The annealing installation at the works in question consisted of three vertical cylindrical furnaces and six bases. The charge weight, the thermocouple location, the method of testing and the method of comparing the test data were standardised. It was desired to make the material as soft as possible. After a number of tests it was found that prolonging the holding time more than 3 hr. caused very little additional decrease in the tensile strength. All subsequent tests were therefore made with 3 hr. holding time, and different annealing temperatures in the 1200-1400° F. range were then explored. Curves were drawn showing the relation between the annealing temperature and the tensile strength, yield stress, elongation and reduction of area. All these curves indicated a softening of the material after annealing at a critical temperature of 1330° F. The standardisation of the annealing process to the above time and temperature for this material resulted in considerable economy in the subsequent manufacturing processes.

A Quick Anneal for High-Carbon High-Chromium Die Steels. B. L. Robinson and R. C. Pruitt (Steel, 1941, vol. 108, June 9, pp. 80-83). The authors refer to a process which they have developed for annealing high-carbon high-chromium tools and dies in 20-30 min. Little information is given of the process itself, but some examples are quoted of broken dies that have been successfully annealed, repaired and hardened.

Furnaces for Shell and Gun Production. F. C. Starr. (Industrial Heating, 1941, vol. 8, May, pp. 477–484, 520–522). The author gives brief descriptions and illustrations of a variety of gas-fired furnaces either under construction or in use in the United States

for the heat treatment of shells, gun barrels and gun parts.

Multiple-Section Wide Doors and Rapid-Quench Method Feature New Furnace. (Industrial Heating, 1941, vol. 8, June, pp. 620–624). A brief description is given of an oil-fired heat-treatment furnace for long bars with a hearth 20 ft. × 4 ft. The interesting feature of this furnace is that the discharging doors extend the whole length of one side. The oil-quenching tank extends for the length of the furnace underneath the door. A cradle is suspended by counterbalance weights against the discharging door. When a bar is ready for quenching it is rolled into the cradle, and the additional weight causes them to sink immediately into the oil.

Modern Heat-Treating Plant Incorporates Many Unique Features. (Heat Treating and Forging, 1941, vol. 27, July, pp. 341–344). A brief description is given of the new factory and office premises of a Chicago company producing heat-treatment furnaces. Some of

the many types of furnace made are illustrated.

Recent Developments in Salt Bath Furnace Practice. W. Adams, jun. (Iron and Steel Engineer, 1941, vol. 18, Sept., pp. 82–87). The author explains the principles of the Hultgrén immersed-electrode salt-bath furnace and describes some installations for case-hardening automobile parts, hardening high-speed tools, age-hardening aluminium, brazing, and the selective heating of shell forgings for the "nosing" operation.

Hardening of Inside Diameters by Inductive Heat Treatment. H. E. Somes. (Iron and Steel Engineer, 1941, vol. 18, July, pp. 39–45). The author describes the "Budd" process of hardening, which is a particular application of induction hardening to the inside surface of cylinders. (See Journ. I. and S.I., 1941, No. II.,

p. 207 A).

Caterpillar Adopts Electro-Magnetic Heating for Hardening Bores of Cylinder Liners for Diesel Engines. (Industrial Heating, 1941, vol. 8, June, pp. 608-610, 674). A brief description is given of the

process of hardening cast-iron liners for Diesel-engine cylinders by an American company manufacturing caterpillar tractors. The

"Budd" induction-hardening process is used.

Heat Treatment of Aircraft Gears. J. L. Buehler. (American Gear Manufacturers' Association: Heat Treating and Forging, 1941, vol. 27, July, pp. 348–350; Steel, 1941, vol. 109, Sept. 1, pp. 78–79). The author's paper which appeared in Iron Age, 1941, vol. 147, June 26, pp. 39–42 is reproduced. (See Journ. I. and

S.I., 1941, No. II., p. 127 A).

Quench-Crack Prevention in Ni-Cr-Mo Forgings. B. Thomas. (Metallurgia, 1941, vol. 24, Sept., pp. 144, 164). The author studied the causes and methods of preventing cracks when low-alloy nickel-chromium-molybdenum steel drop forgings were quenched in oil. It was found that forgings over 2 in. in thickness, even when of regular shape, frequently exhibited these cracks after quenching from 830° C. Tests were carried out by making hardness surveys on batches of forgings quenched from temperatures rising from 760° C. in stages of 10° to 830° C. It was found that with quenching temperatures below 790° C. a proportion of the forgings were soft, and above 800° C. cracks began to appear. Arrangements were therefore made for the buyers to accept forgings quenched from 790° C. instead of from 830° C. as originally specified.

Tempering Air-Hardened Tool Steel. W. H. White. (Metals and Alloys, 1941, vol. 14, Aug., p. 166). The author presents the results of a series of tests in which measurements were made of the amount of distortion occurring in similar castings of special design of an air-hardening tool steel after tempering at various temperatures in the 300–1000° F. range. The steel contained carbon 1·50–1·63%, chromium 11·07–12·20%, molybdenum 0·71–0·84% and vanadium 0·25–0·26%. The changes in hardness and the distortion for different tempering temperatures are shown in tables and graphs. It is of interest that in the 500–900° F. range the hardness remains constant; any increase in the temperature above 900° F. causes an exceedingly rapid increase in hardness and after tempering at 900° F. there is no distortion. The data can be applied to the design of parts of this steel which may not be ground after hardening.

WELDING AND CUTTING

Some Metallurgical Aspects of Metal-Arc Welding of Carbon and Alloy Steels. T. N. Armstrong. (Mechanical Engineering, 1941, vol. 63, Aug., pp. 585–590). The author discusses the changes in hardness which take place across the section of a weld in carbon and in alloy steels. On welding there is no marked hardening of carbon steels with carbon below 0.25%, but with higher carbon the

maximum weld hardness increases rapidly. The effect of carbon is more pronounced than that of any other element. Molybdenum, manganese, chromium and nickel, in descending order of effectiveness, also increase the weld-hardenability of steel. It is generally accepted that carbon-molybdenum steels containing 0.5% of molybdenum and not more than 2.5% of carbon do not require preheating. Tables are presented showing how preheating effects the hardness

of welds in a number of high-strength S.A.E. alloy steels.

Testing the Weld Sensitivity of Structural Steels. H. Buchholtz and P. Bettzieche. (Stahl und Eisen, 1940, vol. 60, Dec. 19, pp. 1145–1151). The authors endeavour to distinguish between "weld sensitivity" (Schweissempfindlichkeit), "weld crack sensitivity" (Schweissrissigkeit), and "weld bead crack sensitivity" (Schweissnahtrissigkeit). They limit the application of the term "weld crack sensitivity" to the gas welding of thin parts. "Weld sensitivity" is understood to mean the tendency of a steel when arc-welded to undergo such changes of properties in the neighbourhood of the weld that the stresses set up by the welding cannot be taken up by deformation, but only by the formation of cracks. The authors also critically examine several German, British and American

methods of testing the weld sensitivity of steel.

Welding Technique for Manganese Steel. D. B. Rice. (Iron Age, 1941, vol. 148, Sept. 11, pp. 54–58). The author describes an investigation of the depth of the work-hardening effect on manganese steel railway crossings and the development of a welding technique for repairing them. Hardness surveys and a microscopical examination of sections of worn "frogs" revealed that appreciable work-hardening took place to a depth of at least 0.80 in. It is recommended that, before welding, the work-hardened metal should be removed to a depth of at least $\frac{1}{4}$ in., and that, when welding, the total heat input should be kept as low as possible. Electrodes, only $\frac{1}{8}$ in. or $\frac{5}{32}$ in. in dia., of nickel-manganese steel should be used first to build up a pad of metal which will absorb the heat from the thicker electrodes used subsequently to build up the major portion of the worn part.

Trouble Shooting. R. C. Stewart. (American Society for Metals: Canadian Metals and Metallurgical Industries, 1941, vol. 4, July, pp. 168–170, 174). The author gives several examples of the detection of the causes of rejection or failure of heat-treated cutting tools, gears and other parts. He describes an unusual but effective method of welding dissimilar steels such as a high-speed-steel tip to a carbon steel shank. For welding two round bars by this process they are firmly clamped in a suitable die, one being fixed and the other movable. While they are held about $\frac{3}{4}$ in. apart, a condenser with which they are connected in series is charged to between 3000 and 5000 V. The two pieces are then rapidly brought together, and when they are about $\frac{1}{16}$ in. apart an arc is established. The mass of the moving part and its clamps is adjusted so that

about 0.0005 sec. after the breakdown of the air gap, the parts are brought into mechanical contact. The extremely high surface temperatures and the rapid motion cause a percussive contact before cooling off. The action is so rapid that practically no flow of heat occurs, and a true surface weld is therefore formed.

Arc Welding of Chrome-Molybdenum Sheet and Tube in the Aircraft Industry. F. R. Kostoch. (Welding Journal, 1941, vol. 20, Aug., pp. 516-519). The author makes recommendations on the equipment and procedure for arc welding chromium-molybdenum sheet and tube for aeroplane construction in accordance with American practice. Some information is given on a device for preventing a crater from forming at the end of a weld when the arc is broken. This consists of a motor-driven rheostat in the generator excitation circuit which is set in motion by the operator pushing a small switch on the electrode holder when the arc is about $\frac{1}{2}$ in. from the end of the weld. The rheostat causes a gradual diminution of the current which results in a slow quenching of the arc, and no puddle of metal remains in which gas-pockets may be formed.

Investigation of the Butt Contact Resistance Welding of Low Carbon Steel. G. V. Nedzvetskiy and E. G. Dumler. (Welding Journal, 1941, vol. 9, Sept., pp. 185–188). An English translation is presented of a paper which appeared recently in the Russian journal Avtgennoe Delo in which the authors give an account of the investigation of the factors affecting the quality of electric resistance welds. Curves are presented which show the decrease in the electrical resistance of round steel bars in end-to-end contact with increasing mechanical pressure on the joint. Increasing the mechanical pressure resulted in a reduction in the width of the heat-affected zone and tended to refine the grain of the metal at the joint. Lowering the current density generally speaking tended to increase the width of the heat-affected zone and to coarsen the grain, but this tendency could be counteracted by increasing the time during which the current flowed.

Spot Welding. Part I. Some Data on Spot Welds in Heavy Gage Mild Steel. Part II. A Photo-Elastic Investigation on the Stress Distribution in Spot Welds. R. F. Tylecote. (Welding Journal, 1941, vol. 20, Aug., pp. 359-S-368-S). In this investigation of the properties of spot welds in mild steel the author devotes Part I. to a presentation of the results of hardness tests and of a microstructural investigation of a spot weld about ½ in. in dia. joining two ¾6-in. strips of mild steel. In Part II. the principles of photoelastic stress determinations are first explained, and a description is then given of the apparatus used by the author for examining the stress distribution in models representing spot welds in mild steel under the influence of shear stresses. Some of the isoclinic and isochromatic stress diagrams obtained are presented. The former diagram shows the points where the principal stresses have

the same inclination, and it is one obtained with plane polarised light. The latter diagram is obtained with circularly polarised light, and in it the zones of equal principal stress difference are

indicated by the same colour.

Black Heat Temperatures. T. E. Lloyd. (Iron Age, 1941, vol. 148, July 24, pp. 41–46). The author makes recommendations on the degree of preheating which should be applied to carbon and alloy steels, cast irons and some non-ferrous metals prior to welding them or to cutting with the oxy-acetylene torch. As the preheating temperatures are all in the black-heat range, the use of a proprietary brand of temperature-indicating pellets is advocated. These pellets are graded to melt at fixed temperatures as follows: in steps of 25° F. in the range 100–350° F., and in 50° F. steps in

the range 350–1600° F.

Some Developments in the Repair by Welding of Finished-Machined Castings. C. G. Lutts and P. Ffield. (Journal of the American Society of Naval Engineers, 1941, vol. 53, Aug., pp. 491–501). The authors explain that the distortion of castings which have been repaired by welding is caused by stresses of two kinds, one due to shrinkage of the filler metal and the other to differential expansion arising from temperature gradients set up during welding. They consider that the decrease in the thickness of steel due to scaling in a stress-relieving furnace is negligible. They then describe the welding procedures adopted on examples of three groups of castings. In the first group a certain amount of distortion could be tolerated and no special precautions to avoid it were adopted. The casting of the second group could be re-machined to correct a limited amount of distortion. The third example was a finish-machined casting where no machining could be permitted after the welding repair.

Building Up and Hard Facing in the Steel Plant. L. Ames. (Iron and Steel Engineer, 1941, vol. 18, Aug., pp. 40-47). The author describes several applications of oxy-acetylene, metallic-arc and carbon-arc welding for maintenance purposes in a steel plant. The examples include building up worn cast-iron pistons with bronze, building up worn or broken gear-teeth, rolling-mill guides,

wobblers, rail ends, crossings and switches.

Welded Open-Hearth Auxiliaries. C. C. Keyser. (Iron and Steel Engineer, 1941, vol. 18, July, pp. 52–57). The author describes several applications of electric welding at the open-hearth plant of the Bethlehem Steel Co. Particulars are given of welded charging boxes, hard-surfaced charging machine rams, hot metal runners, brick trays, slag bowls, ladles and frames for ingot cars.

MACHINING

Large-Scale Production Results with Lead-Bearing Steels. (Metallurgia, 1941, vol. 24, Aug., pp. 99–101). Some of the advantages of using lead-bearing steels are discussed and illustrated by comparing the methods of production and production times for a number of articles such as cycle spindles, bushes, grease nipples, set-screws and bolts when made of lead-free and lead-bearing free-cutting steels. Additional information is also given of extensive tests on the machining of 40-mm. shells of lead-bearing steel which showed a very considerable saving in the machining time.

When You Machine Stainless. W. B. Brooks. (Machinist, 1941, vol. 85, Oct. 18, pp. 643–644). The author makes the following recommendations for machining 18/8 stainless steel: (1) The tool should have liberal rake and clearance angles; (2) use liberally cooling agents containing sulphur or sulphur and chlorine; (3) hone the tools after grinding; (4) use a generous feed, and cut below the work-hardened skin left by the previous cut; and (5) reduce the cutting speed 20–50% below that used for machining mild

steels.

Finishing Sprayed Metals. W. C. Reid. (Steel, 1941, vol. 109, Aug. 18, pp. 90–94, 104). The author points out that the machining properties of sprayed metal surfaces are different from those of the base metal. Particulars of the tools, grinding wheels and of the machining and grinding speeds which should be used for a number of ferrous and non-ferrous sprayed metal surfaces are given.

The Manufacture and Use of Cemented Carbides. H. Burden. (Coventry Engineering Society Journal, 1941, vol. 22, Mar.-Apr., pp. 31-62). The author gives a comprehensive account of the manufacture of cemented carbides and their properties, pointing out the relation between the properties of a finished tool and those of the materials from which it is made. Tool design is discussed and many illustrated examples of machining operations with cemented-carbide tipped tools are given.

How to Grind Steel-Cutting Carbide Tools. G. G. Thompson. (Iron Age, 1941, vol. 148, Sept. 11, pp. 41–44). The author describes the grinding procedure and gives details of the correct angles to which carbide-tipped tools for machining steel and cast iron should

be ground.

CLEANING AND PICKLING OF METALS

Metal Cleaning. W. F. Sherman. (Iron Age, 1941, vol. 148, July 24, pp. 38-40). The author gives a short description of a salt-bath method of cleaning iron and steel billets, castings and

sheets. The material used is known as "Kolene Kleaner," and this is melted and kept in a bath at 550–600° F. in which the part to be cleaned is immersed. The first action is that of degreasing by the oxidation of carbonaceous matter, oils and greases. The second action is that of converting the lower oxides, of which mill-scale and heat-treatment scale are largely composed, to the more soluble higher oxides. These are finally removed by pickling in a weak acid for a very short time.

The Contamination and Electrolytic Cleaning of Cold Rolled Steel. E. H. Lyons, jun. (Electrochemical Society, 1941, Oct., Preprint No. 80–12). After describing the electrolytic process of cleaning cold-rolled strip, the author discusses how the conditions of rolling, particularly the cooling agent, affect the efficiency of the cleaning. The use of cooling oils more resistant to breakdown by decomposition, oxidation or polymerisation, and the regulation of the rolling conditions so as to reduce the breakdown of the oil are

advocated.

Sulphuric Acid Pickling of Steel. O. G. Pamely-Evans. (Iron and Steel, 1941, vol. 14, Aug., pp. 416–417). In discussing the removal of scale from steel by sulphuric-acid pickling the author criticises the theory that the scale consists of three layers of ferrous oxide, ferroso-ferric oxide and ferric oxide respectively, and the deductions made from this theory. The author doubts that the ferrous oxide layer will be kept in this most reduced state of oxidation by being in contact with iron, and considers it more likely that a dynamic condition of interpenetration of higher oxide and iron crystals exists. He agrees that the ferroso-ferric oxide is formed, but believes that the outer layer of ferric oxide is almost non-existent. It is suggested that solution of iron from the permeated layer of oxide is the main chemical action, and that the mechanical loosening of scale by this causes the "cleaning."

J. & L. Installs Mechanical Scarfer. T. C. Campbell. (Iron Age, 1941, vol. 148, Sept. 4, p. 45). The author briefly describes a bloom conditioning machine recently installed at the rolling mill of the Jones and Laughlin Steel Corporation, Pittsburgh. This is a flame-scarfing machine equipped with four banks of nozzles which cause the oxy-acetylene flames to impinge on all four sides of the bloom. The machine is placed in the mill next to the billet shears, and the blooms can be scarfed sufficiently rapidly not to slow up the speed of production. The gas pressures can be adjusted to remove from $\frac{1}{64}$ in. to $\frac{1}{8}$ in. of steel. The scale which is produced consists of about 80% of steel and 20% of iron oxide; this is reduced to a small size by high-pressure jets of water and is

subsequently charged into the steel furnaces.

COATING OF METALS

Filtration of Electroplating Solutions. E. Armstrong. (Metal Treatment, 1941, vol. 7, Autumn Issue, pp. 92-98). The author discusses the origin of the solids which form in electroplating solutions and describes methods of removing them. The filters described include filter cones and presses, the candle-type filter and the "Meta" filter. The candle-type filter is made up of a number of cylinders of a porous ceramic-like material arranged in parallel: the solution to be filtered is forced from the outside inwards to the 'centre of the hollow cylinders or candles, whence it is piped back to the vat. In the Meta filter columns of metal rings are fitted on central drainage rods. These rings are thin and have three bosses a few thousandths of an inch in height, which separate them and provide filtration channels. A filter unit comprises a number of ring-stacks mounted in parallel in the same chamber. The solution to be filtered is forced through the packs from the circumferential edges inwards. A detailed description and drawing of a Meta filter are given, together with operating instructions, and data regarding filter pumps, plant layout and capacity are discussed.

Rectifiers for Electroplating. A. Bregman. (Iron Age, 1941, vol. 148, Sept. 11, pp. 48–53; Sept. 18, pp. 72–76; Sept. 25, pp. 43–47). The author explains the principles on which current rectifiers work, discusses the characteristics of different types and the advantage of using them rather than motor generators, and describes some of the types available for electro-plating purposes. Some information on their efficiency and maintenance is also given.

General Principles and Methods of Electroplating. W. Blum, A. O. Beckman and W. R. Meyer. (Electrochemical Society, 1941, Preprint No. 80–33). The authors present a comprehensive review in four parts of the whole subject of electroplating. Part I. is a brief introduction. In Part II. several processes are described in detail. Part III. is confined to the testing and control of solutions; the properties of deposited coatings are dealt with in Part IV. This paper may be considered as a general introduction to the subject of plating, whilst details of the plating of particular metals were given in other papers read at the 1941 meeting of the Electrochemical Society. Abstracts of these papers will be found on pp. 31 A and 32 A.

Chromium Plating. G. Dubpernell. (Electrochemical Society, 1941, Preprint No. 80–24). The author gives information on the preparation of chromium-plating baths, the cleaning of articles to be plated, obtaining the optimum plating conditions and testing chromium coatings. There are 105 references to the literature.

Hard Chrome for Tougher Tools. No. 1. Plating for Life—Not Looks. No. 2. Proper Plating Procedure. No. 3. Control of Plating Baths. No. 4. How Thick a Plate? R. F. Yates. (Machinist,

1941, vol. 85, July 26, pp. 327–330; Aug. 9, pp. 381–383; Aug. 23, pp. 426–428; Sept. 6, pp. 477–479). In the first part of this series of articles the author gives many examples of the increased life obtained by the hard chromium plating of tools and parts subjected to severe wear, such as gauges, twist-drills, rolls for paper mills and dies for moulding plastics. In the second part the procedure for plating different parts is described. It is stressed that before the actual plating current is applied, a reverse current, with the part as the anode, must be passed for 15–20 sec. In applying the plating current, this can be stepped up as the temperature increases, and the rate of deposition is thus increased. In the third part the control of the plating bath is discussed in more detail and procedures are given for checking the chromic acid content, the sulphuric acid content and the amount of trivalent chromium present. In the fourth part mechanical, magnetic and X-ray methods of determining the thickness of chromium plating are described.

Nickel Plating. W. L. Pinner, G. Soderberg and E. M. Baker. (Electrochemical Society, 1941, Preprint No. 80–23). The authors review the development of nickel-plating practice with particular reference to the Watts bath and to the operation and characteristics

of baths for bright nickel plating.

Cobalt Plating. G. Soderberg, W. L. Pinner and E. M. Baker. (Electrochemical Society, 1941, Preprint No. 80–32). The authors review the literature on cobalt plating, give formulæ for cobalt-sulphate and cobalt-chloride baths, and describe the process and

methods of testing the coatings.

Iron Deposition. C. T. Thomas. (Electrochemical Society, 1941, Oct., Preprint No. 80–15). The author reviews the history of the development of electrolytic processes of depositing iron and describes in detail the operation and maintenance of the ferrous-sulphate and the ferrous-chloride processes and the properties of the deposits produced.

Cadmium Plating. G. Soderberg and L. R. Westbrook. (Electrochemical Society, 1941, Preprint No. 80–27). The authors describe in detail the principles and practice of cadmium plating in baths

prepared by dissolving cadmium oxide in sodium cyanide.

Alloy Plating. C. L. Faust. (Electrochemical Society, 1941, Preprint No. 80–18). The author reviews the literature on the simultaneous deposition of two or more metals to form alloy coatings. He discusses the principles of the process, some of the anodes used, the function of bath constituents and the influence of certain variables.

Acid Zinc Plating. E. H. Lyons, jun. (Electrochemical Society, 1941, Oct., Preprint No. 80–16). The author describes the electrolytic process of galvanising, giving particulars of acid bath and cyanide bath solutions, the function of the bath constituents, current density, operating temperature, the zinc anodes, the preparation of the base metal and methods of testing the deposits. A bibliography of 52 references is appended.

Cyanide Zinc Plating Baths. R. O. Hull and C. J. Wernlund. (Electrochemical Society, 1941, Preprint No. 80–36). The authors point out the advantages and limitations of cyanide zinc baths for galvanising and producing bright zinc coatings. They describe and discuss the composition of suitable baths and their control, the selection of addition agents and the current densities used. There are 45 references to the literature.

Alkaline Tin Plating. F. F. Oplinger and F. Bauch. (Electrochemical Society, 1941, Preprint No. 80–25). The authors describe the principles, operating conditions and characteristics of the process of tinplating with alkaline baths made up of sodium stannate,

caustic soda, sodium acetate and hydrogen peroxide.

Electrodeposition of Tin from Acid Solutions. P. R. Pine. (Electrochemical Society, 1941, Preprint No. 80–31). The author describes the development of the process of tinplating in stannons-sulphate/sulphuric-acid baths and compares the advantages and limitations of this and the alkaline processes. The acid bath will deposit tin from two to three times faster than the alkaline bath under comparable conditions, and it is therefore used for the continuous process of tinning steel strip. Full details of the preparation of the solution, current density and methods of control for the acid process are given.

PROPERTIES AND TESTS

Determining the Elastic Modulus by Applying Alternating Stresses to the Test-Piece. G. Haupt. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 12, pp. 203-212). The author surveys the theory and practice of methods of determining the elastic modulus of steel. The testing appliances described and discussed fall into two groups: those used for testing the validity of oscillation formulæ, and those with which determinations of elastic moduli can be made for practical purposes. The methods and apparatus described include: (1) The highfrequency tension-compression technique of Esau and Voigt, with which heavy loads can be applied; (2) the double-pendulum method of Le Rolland and Sorin; (3) that of Güttner; (4) that of Bancroft and Jacobs; (5) the Förster-Köster apparatus; (6) Hornibrook's apparatus; (7) that of Aoyama and Fukuroi; and (8) the Thyssen elastometer. The results obtained with some of these apparatus are discussed.

Mechanical Properties of Iron-Manganese Alloys. F. M. Walters, jun., I. R. Kramer and B. M. Loring. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1369: Metals Technology, 1941, vol. 8, Sept.). The authors report on some investigations of the tensile strength and hardness of

specially prepared iron-manganese alloys of high purity. Specimens were prepared with manganese contents ranging from 4% to 20%. With up to 10% manganese the austenite on cooling transforms into ferrite and the transformation temperature decreases with increasing manganese. With more than 14% manganese the austenite transforms partly into the closely packed hexagonal ϵ -phase, the alloys having a low elastic limit and a high elongation. At between 10% and 14% manganese both ferrite and the ϵ -phase are formed, and the alloys in this range have the highest tensile strength. The authors compare their results with those Hadfield obtained (see Journ. I. and S.I., 1927, No. I., p. 304), and consider that the brittleness noted by the latter was probably due to the rather high carbon and phosphorus contents of the alloys he used.

No More Fissures in Slowly Cooled Rails. T. J. Dolan. (Metal Progress, 1941, vol. 40, Aug., pp. 198–200). The author considers the causes of transverse fissures or shatter cracks in rails. One of the causes is the non-evolution of hydrogen from rapidly cooled rails. It has been found that these cracks actually form at or below 300° F., but the rate of cooling at temperatures above that limit determines whether the cracks occur. Two cooling schedules have been developed in the United States which effectively prevent the formation of these cracks. One is to cool the rails in insulated containers from 700° F. to 300° F. in not less than 7 hr. The other is to hold the rails at either 1100° F. for 3 hr. or 900° F. for 4 hr., after which they can be rapidly cooled to room temperature.

Railroad Failures in Track and Cars. R. McBrian and P. A. Archibald. (Metal Progress, 1941, vol. 40, Aug., pp. 189–191). The authors describe some examples of failures in railway material and discuss their causes. The examples include the fracture of an arch bar in the side-frame of a truck, fatigue cracks in fish-plates, and a broken truck axle caused by overheating of the journal.

Thoughts on the Problem of Wear. K. Daeves. (Stahl und Eisen, 1940, vol. 60, Nov. 7, pp. 1007–1008). The author explains the mechanism of wear and suggests the lines on which research on the problem of wear should proceed. He considers that it is necessary to examine quantitatively wear phenomena of similar nature and to keep these separate from other wear phenomena, and then to investigate how the conditions which have a favourable effect on wear can be promoted.

Progress with Leaded Steels. W. B. Wragge. (Mechanical World and Engineering Record, 1941, vol. 110, Sept. 26, pp. 209–211). The author presents data on the machinability of lead-bearing mild steel and some lead-bearing alloy steels, and the

increased tool life obtained when turning these steels.

Magnetic Testing Simplified. J. A. Sams and E. A. Stack. (Iron Age, 1941, vol. 148, Aug. 28, p. 41). The authors describe a simple method of making a record of the position of defects found on a steel surface by the magnetic powder process. This is done

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by placing a strip of gummed cellulose tape over the surface. There is always sufficient residual magnetic powder on the crack to adhere to the gummed surface, and when the strip is removed and mounted on white cardboard, the adhering powder shows up as a dark line

at the exact position of the original crack.

The Instability of Low-Expansion Iron-Nickel-Cobalt Alloys. I. R. Kramer and F. M. Walters, jun. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1370: Metals Technology, 1941, vol. 8, Sept.). The authors report on an investigation of the coefficient of expansion of a number of iron-nickel-cobalt alloys falling within the following range of composition: iron 49–62%, nickel 27–37% and cobalt 0–22%. The expansion of specimens held at 480° C. for nine months was measured with a dilatometer, and filings held for about two months at various temperatures were examined by X-rays to determine changes in structure. It was found that although these alloys have a low coefficient of expansion at normal temperatures, there is a considerable increase in the expansion in the range $360-540^{\circ}$ C. and that the γ -phase is unstable in this range, partial transformation to

the a-phase taking place.

The Creep Recovery of a 0.17 per cent. Carbon Steel. A. E. Johnson. (Proceedings of the Institution of Mechanical Engineers, 1941, vol. 145, Oct., pp. 210-220). The author describes an investigation, for the case of a 0.17% carbon steel, of the relation between the recovery after a creep test and the conditions of stress, temperature, period of test and strain during the test. Creep and recovery tests were made with apparatus capable of measuring creep rates of the order of 10-8 in. per in. per hr. at temperatures of 425°, 455° and 485° C. for periods of 0.2, 2, 20 and 145 hr. following conclusions were arrived at: (1) At a given temperature, and for any particular period of creep test, the recovery curves at all stresses are geometrically similar. (2) At each temperature, and for any fixed period of creep, recovery varies directly as the stress applied. (3) Recovery increases with temperature over the range 350-550° C., from about 3% of the initial elastic strain at 350° C. to 52% at 550° C. Over the small range of temperature $425-485^{\circ}$ C. the recovery seems to increase approximately linearly with temperature. (4) As the period of creep test preceding recovery is increased, the amount of recovery at a given stress also increases up to a maximum value at the commencement of the period of minimum creep rate, and does not further increase while the minimum creep rate is maintained. (5) The time necessary to complete the recovery of the material increases with the duration of creep test up to the period of minimum rate, and does not further increase while the minimum rate is maintained. (6) No simple relation between creep strain and recovery strain could be found. (7) The results appear to confirm that recovery is bound up with the partial or complete release of stress concentrations built up during the creep test, and that stress concentrations become more intense as the creep test proceeds, thereby increasing the amount of recovery. (8) The superposition theory of Boltzman, and modifications of this theory by Bennewitz and Becker, as well as Chalmers' theory, all fail to represent the results of the tests on

the 0.17% carbon steel.

Some Creep Properties of 16Cr-13Ni-3 per cent. Mo Steel. H. D. Newell. (Metals and Alloys, 1941, vol. 14, Aug., pp. 173-180). The author discusses the results of creep tests on steels containing chromium 16%, nickel 13% and molybdenum 3%. Some tests at temperatures in the 600-1600° F. range on steel of this type containing only 0.074% of carbon revealed that at 1100° F. the material yielded in a rapidly recurring series of slips, not noted at 1200° F. and above, less notable and of lower frequency at 1000° and 900° F., and only slightly discernible at 800° and 600° F. The same alloy steel with carbon 0.11% has some susceptibility to aqueous corroding agents after long continued exposure to temperatures in the 1100-1400° F. range, but experience has shown that corrosion of this type is not encountered in the usual cracking or other processes used on oils and hydrocarbon gases provided that condensation of moisture does not take place on external surfaces of tubes during inoperative periods. Hence it appears that the creep strength of the 0·11%-carbon alloy may be utilised in equipment for such processes if proper precautions are taken; these would include the removal of sulphate deposits from tube

surfaces and oiling them during shut-down periods.

Hydrogen in Steel and Cast Iron and Defects in Applied Coatings. C. A. Zapffe and C. E. Sims. (Metals and Alloys, 1941, vol. 13, Apr., pp. 444-447; May, pp. 584-589; June, pp. 737-742; vol. 14, July, pp. 56-60). In the first part of this series of articles the authors discuss some of the sources from which steel can absorb hydrogen and the detrimental effects this hydrogen has on enamel coatings during the firing process. In the second part some experiments are described in which specimens of steel plate were drilled from the edge with three parallel holes; iron oxide was placed in one hole, graphite in the second and the third was left empty. The holes were sealed, the plate was given a light pickling treatment and was then enamelled and fired. After several refirings of the ground coat, all the hydrogen in the unfilled cavity was removed and a cover coat was then applied; after firing this, no trace of hydrogen from the unfilled cavity was visible, except for a few small blisters from hydrogen that had diffused laterally; the centre hole containing graphite could be traced by a few blisters, thus showing that graphite retarded the release of hydrogen from the metal; the third hole was sharply outlined with blisters with very little lateral diffusion. The manner in which the carbon in cast steel affects the absorption of hydrogen on heating and the emission of hydrogen on cooling, and the influence of the direction of rolling on the diffusion of hydrogen are also discussed in this part. In the third part the effect of the temperature and concentration of an acid on the absorption and evolution of hydrogen by steel is illustrated by graphs and discussed. It is stated that some elements, particularly those in the 5th and 6th groups of the Period Table, increased the ratio of absorbed to liberated hydrogen for steel to a remarkable extent; small amounts of arsenic, for example, can increase the hydrogen absorption 100 times. In the concluding part some examples are given of the delayed formation of pinholes and "fish scales" due to the time taken by occluded hydrogen to reach the under surface of an enamel coating and build up sufficient

pressure to burst it.

Influence of Chromium and Molybdenum on Structure, Hardness and Decarburization of 0.35 per cent. Carbon Steel. R. F. Miller and R. F. Campbell. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1345: Metals Technology, 1941, vol. 8, Sept.). The authors report on an investigation of 16 steels containing different combinations of chromium and molybdenum in amounts up to 5% of each element, the object being to determine the microstructure and hardness obtained after different heat treatments. In air-cooled steels, the addition of more than 0.5% of chromium changes the pearlitic structure of plain 0.35% carbon steel to an acicular carbide-ferrite aggregate; further additions of chromium promote the formation of martensite. The presence of 0.5% of molybdenum is more effective in forming the acicular structure and increasing the hardness than the presence of the same amount of chromium, but further additions of chromium are more effective than molybdenum in forming martensite. The first traces of martensite are found in steels containing about 2% of either chromium or molybdenum. When both elements are present, chromium is more effective than molybdenum in forming martensite and increasing the hardness. The depth of decarburisation which occurs during heat treatment is decreased by chromium, but is increased by molybdenum even in the presence of chromium.

Some Effects of Titanium on Low Carbon 1 per cent. Chromium Steel. J. N. Pappas and M. Cohen. (Iron Age, 1941, vol. 148, July 31, pp. 29–34). The authors report on an investigation of the effect of titanium additions on the properties of steels containing carbon 0·18–0·22% and chromium 0·98–1·06% some of which also contained vanadium. In particular the influence of titanium on the effect of the heat treatment was examined. The following conclusions were arrived at: (1) The addition of aluminium, titanium or vanadium to a steel of the above type raises the temperature at which grain-coarsening occurs, and the effect of these elements in this respect decreases in the order named; (2) the addition of titanium lowers the tensile strength and increases the ductility and impact strength; (3) the deoxidation of this steel with titanium produces a better combination of properties than does deoxidation

with aluminium; (4) both aluminium and titanium inhibit airhardening in this steel after normalising at temperatures up to 1850° F., but after normalising at 2050° F., the hardenability on air cooling of the titanium-bearing steels increases markedly; and (5) the combined use of aluminium and titanium may be advantageous in attaining a given set of properties with less titanium than would be required in the absence of aluminium.

Pre-Heat-Treated Alloy Steel. (Iron Age, 1941, vol. 148, Sept. 4, pp. 54–55). Brief particulars are given of a chromium-nickel-molybdenum steel (composition not stated) known as "Elastuff 44." This steel is marketed in round bars in the heat-treated state, and it requires no further heat treatment after machining. It is claimed that bars up to 6 in. in dia. are of uniform hardness

(Rockwell C 44) over the whole cross-section.

High-Speed Steels in U.S.S.R. (Iron and Coal Trades Review, 1941, vol. 143, Oct. 3, p. 313). Some particulars are given of the properties of high-tungsten and low-tungsten high-speed steels developed in the U.S.S.R. Tables of the analyses, heat treatment and properties of the alloys as determined in investigations by Iwanow and by Braun, Wlassow and Ewenbach are presented.

Specifying Materials in Design of Pressure Vessels. A. Grodner. (Machine Design, 1941, vol. 13, Aug., pp. 45–48, 124–126). The author discusses the requirements for boiler steel, stainless steel and carbon steel clad with stainless steel for the manufacture of vessels to operate at high temperatures and pressures, as specified by the code of the American Society of Mechanical Engineers.

Why Gray Iron Piston Rings for Aircraft Engines? P. Lane. (Foundry, 1941, vol. 69, Aug., pp. 50–53, 112–113). The author points out the special properties of grey cast iron which render it a very suitable metal for aero-engine piston-rings. These include the fact that it causes little wear to either steel cylinder bores or the grooves of aluminium pistons, and that it retains its "spring qualities" at temperatures up to 600° F.

Deep Drawing Steel. L. W. Heise. (Metal Progress, 1941, vol. 40, Aug., pp. 163–166). The author describes and illustrates numerous examples of deep-drawn steel parts for automobiles and discusses the composition, microstructure and properties of steel

for making them.

On Testing the Wall Thickness of Castings. B. M. Thornton and W. M. Thornton. (Foundry Trade Journal, 1941, vol. 65, Oct. 16, pp. 253–254). The authors describe the principles of an instrument for the determination of the wall thickness of castings from one side only, and a practical example of its application. The instrument is portable, robust, easy to operate and is independent of external electric power supply. The method consists of comparing the electrical resistance of the metal wall under test with that of a similarly shaped wall of the same material of which the thickness is known. A current of not more than 10 amp. at

up to 12 V. is required, and is applied by two contacts held against the wall of the casting at a distance of 1 in. to 12 in. apart. The current in the circuit is adjusted by varying a rheostat until the potential drop indicated by a galvanometer connected across two points close to the current contacts reaches a predetermined fixed value. The thickness of the wall corresponding to the current registered by the ammeter on the instrument is then obtained from a calibration curve.

METALLOGRAPHY AND CONSTITUTION

Vertical Illumination for Macros. G. K. Manning. (Metal Progress, 1941, vol. 40, Aug., pp. 172–173). The author describes the set-up of apparatus for obtaining macrographs with vertical illumination and presents for comparison three pairs of macrographs of steel in which vertical and oblique illumination have been used.

Cibanite Mountings for Metallurgical Specimens. B. Walsh. (Iron Age, 1941, vol. 148, July 24, pp. 48–49). The author describes the procedure for mounting metallographic specimens in Cibanite and for the preparation of the Cibanite mould from the powder which consists of a condensation product of aniline, hydrochloride

and formaldehyde.

The Evaluation of X-Ray Back-Reflection Pictures. H. Neerfeld. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 13, pp. 213–216). The author surveys various methods of evaluating X-ray back-reflection pictures and proposes some modifications with the object of simplifying the procedure. One suggested procedure for rapidly determining the lattice constant is that of projecting the X-ray film on to a suitable nomogram; another more accurate method is to measure the distance between the lines with a glass rule or a comparator in the usual way and to use a nomogram, or a special slide rule, to simplify the calculation of the lattice constant.

Metallographic Examination Standardized. H. Diergarten. (Verein Deutscher Ingenieure: Iron Age, 1941, vol. 148, July 24, pp. 33–37; July 31, pp. 38–43, 96). An English translation is presented of the author's account of a standard method for the numerical classification of the inclusions and the structure of steel as revealed by the microscope. The method was developed in the laboratories of Vereinigte Kugellagerfabriken A.-G. The sections are examined at a magnification of 100, with a field 75 ± 5 mm. in dia. The classification number consists of four digits divided into three groups. The first digit indicates the general character of the section, e.g., 1 = slag inclusions, 2 = carbide segregation, 3 = normalised or annealed structure. The second group of two digits indicates the class and shape of the inclusions, e.g., whether

oxides or sulphides, and whether round, oval or thread-like. The fourth digit indicates the size and frequency of the inclusions. Several series of micrographs are reproduced with their correspond-

ing classification numbers.

Microstructural Characteristics of High-Purity Alloys of Iron and Carbon. T. G. Digges. (Journal of Research of the National Bureau of Standards, 1941, vol. 27, July, pp. 65–79). The author studied the microstructural characteristics of slowly cooled highpurity iron-carbon alloys of hypereutectoid composition and of the influence of certain impurities (oxygen, aluminium and hydrogen) on their structure. The alloys were prepared from 17 irons, varying in degree of purity, by carburising them in a mixture of hydrogen and benzene vapour. The structure of the carburised irons of highest purity, free from aluminium and with a total of less than 0.009% of identifiable impurities, contained free ferrite in the hypereutectoid zone. If oxygen were responsible for this, then a minute amount was sufficient and just as effective as larger quantities. Aluminium in excess of about 0.001% prevented the formation of free ferrite, and alumina was not the factor responsible for its formation. The hydrogen dissolved in the irons during carburisation had no detectable effect on the precipitation of ferrite. The experimental results indicated that a structure containing free ferrite is characteristic of high-purity alloys of iron and carbon of hypereutectoid composition that have been slowly cooled from the austenitic condition.

Austenite Grain Size-Effects, Manipulations and Limitations. A. E. Focke. (American Society for Metals: Iron Age, 1941, vol. 148, Aug. 28, pp. 35–40; Sept. 4, pp. 51–53). The author discusses the theory and practical application of factors affecting the grain size of austenitic steels. He describes methods of revealing the austenite grains and the A.S.T.M. method of measuring and recording the grain size, and considers, with many references to the literature, how the grain size of the austenite can be controlled and how it affects hardenability, the rate of carbon penetration when car-

burising, and the fatigue strength.

The New Type of the A_3 Transformation of the Fe-Ni Alloy by Supercooling and the Mechanism of the Formation of the Intermediate Phase during Quenching of the Eutectoid Alloy. K. Iwasé and S. Takeuti. (Nippon Kinzoku Gakkai-Si, 1941, vol. 5, Feb., pp. 68-76). (In Japanese).

CORROSION OF IRON AND STEEL

Knowledge and Problems in the Corrosion-Investigation Field. K. Daeves. (Stahl und Eisen, 1940, vol. 60, Dec. 26, pp. 1181-1186). In this discussion of the planning of corrosion investigations the author states that the results of laboratory tests cannot be applied to the long-time behaviour of steels in the atmosphere and in water. Corrosion investigations should be divided into work on two main groups of materials, viz.: (1) Carbon and low-alloy steels and cast iron; and (2) corrosion- and heat-resisting steels. The first group should be sub-divided into unprotected and coated ferrous metals, and the second group into stainless steels and non-scaling steels. Finally, the behaviour of the materials of each sub-division in the atmosphere, in liquids and soil or solid salts form subjects for separate study. The author has drawn up a comprehensive table based on this classification which shows what subjects have already been investigated and some of the problems which still remain to be solved.

Simple Method for Detecting Susceptibility of 18/8 Steels to Intergranular Corrosion. H. W. Russell, H. Pray and P. D. Miller. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1343: Metals Technology, 1941, vol. 8, Sept.). The authors describe a rapid electrolytic test for the detection of carbide precipitation in 18/8 steels. When the test is applied under proper conditions and the spot produced on the metal is viewed by oblique illumination, the appearance of smooth dark grains outlined by bright boundaries indicates susceptiblity to intergranular corrosion. The formation of a smooth test spot indicates non-susceptibility; a spot that shows attack at areas other than the grain boundaries indicates that a harmless form of carbide precipitation may occur. The cell consists of an open lead tube, one end of which is sealed to the surface under test by a piece of rubber tubing slipped over the lead. The electrolyte is made up of 60% sulphuric acid to which is added 5 c.c. per litre of Glycyrrhiza extract. To produce a test spot about \(\frac{3}{8} \) in. in dia. requires a current of 1.5 amp. at about 5 to 7 V. The treatment takes 3 min., and very little surface preparation is necessary. This test appears to be applicable to both wrought and cast materials of various carbon contents. The effect of time and temperature on the degree of carbide precipitation can be followed by this test. The test is non-destructive and can be applied to completed structures.

BOOK NOTICE

American Institute of Mining and Metallurgical Engineers. Transactions, Volume 143. Institute of Metals Division. 8vo, pp. 350. Illustrated. New York, 1941: The Institute. (Price \$5.)

This volume is the fifteenth of a series constituting the official proceedings of the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers. It includes papers pre-

sented at the Cleveland Meeting, October 1940, and the New York Meeting, February 1941. It contains 29 papers, and is one of the largest of the series published. Although devoted to non-ferrous metallurgy, much valuable information can be found in its pages which is of interest to the ferrous metallurgist. It includes an important lecture by a leading physical metallurgist, Professor G. Sachs, on "Some Fundamentals of the Flow and Rupture of Metals." In addition it also contains the following papers: Internal Friction of Single Crystals of Copper and Zinc, by T. A. Read; Time and Temperature Effects in the Deformation of Brass Crystals, by H. L. Burghoff and C. H. Mathewson; Flow of Solid Metals from the Standpoint of the C. H. Mathewson, Flow of Solid Metals from the Standpoint of the Chemical-Rate Theory, by W. Kauzmann; Deformation and Recrystallization of Copper and Brass—Hardness, Microstructure and Texture Changes, by R. M. Brick and M. A. Williamson; Corrosion of Copper and Alpha Brass—Film-Structure Studies, by J. H. Hollomon and J. Wulff; Some Practical Observations on Inverse Segregation, by D. R. Hull; Self-Diffusion of Silver, by W. A. Johnson; On the Equilibrium Solidification of Solid Solutions (Abstract), by M. Cohen and W. P. Kimball; Measurement of Irreversible Potentials as a Metallurgical Research Tool, by R. H. Brown, W. L. Fink and M. S. Hunter; X-Ray Study of the Solid Solubility of Lead, Bismuth and Gold in Magnesium, by F. Foote and E. R. Jette; Mechanism of Precipitation from the Solid Solution of Silver in Aluminium, by C. S. Barrett, A. H. Geisler and R. F. Mehl; Precision X-Ray Study of the High-Silver Aluminium-Silver Alloys, by F. Foote and Eric R. Jette; X-Ray Analysis of Hot-Galvanized Heat-Treated Coatings, by F. R. Morral and E. P. Miller; Creep and Recrystallization of Lead, by A. A. Smith, jun.; Tensile Properties of Rolled Magnesium Alloys Binary Alloys with Calcium, Cerium, Gallium and Thorium, by J. C. McDonald; Grain Orientation of Cast Polycrystalline Zinc, Cadmium and Magnesium, by G. Edmunds; Studies upon the Corrosion of Tin-Effects of Cations in Carbonate Solutions and Effects of Alloying Elements by G. Derge and H. Markus; Effect of Composition on Physical and Chemical Properties of 14-carat Gold Alloys, by T. C. Jarrett; Beneficial Effects of Zirconium in Cast Nickel-Silicon Bronzes, by F. R. Hensel, E. I. Larsen and A. S. Doty; Study of the Metallography and Certain Physical Properties of Some Alloys of Cobalt, Iron and Titanium, by C. R. Austin and Carl H. Samans; Effect of Cold-Work upon Electrical Conductivity of Copper Alloys, by D. K. Crampton, H. L. Burghoff and J. T. Stacy; Low-Temperature Oxidation of Single Crystals of Copper by B. Lustman and R. F. Mehl; Preparation and Some Properties of High-Purity Copper by J. S. Smart, jun., A. A. Smith, jun., and A. J. Phillips; Solubility of Sulphur. Dioxide in Molten Copper, by C. F. Floe and J. Chipman; Solubility of Oxygen in High-Purity Copper, by A. Phillips and E. N. Skinner, jun.; Hydrogen Embrittlement of Pure Copper and of Dilute Copper Alloys by Alternate Oxidation and Reduction, by F. N. Phines and W. A. Anderson; Coalesced Copper—Its History, Production and Characteristics, by H. H. Stout; Coalescence Process for Producing Semifabricated Oxygen-Free Copper, by J. Tyssowski.

MINERAL RESOURCES

Minnesota's Iron Mining Industry. E. E. Hunner. (Mining and Metallurgy, 1941, vol. 22, Aug., pp. 395–399). The author describes the geography and geology of the ore deposits and the

economy of the Lake Superior iron mining industry.

Mining Practice and Mine Transportation on Minnesota's Iron Ranges. G. J. Holt. (Mining and Metallurgy, 1941, vol. 22, Aug., pp. 400–404). The author gives an account, with numerous illustrations, of the mining methods employed at the iron-ore mines in Minnesota in the region to the west of Lake Superior. Great advancement has been made in the equipment for open-face working, and it is noted that many steam locomotives have been replaced by electric, Diesel or Diesel-electric locomotives.

ORES-MINING AND TREATMENT

Beneficiating Minnesota Iron Ores. T. B. Counselman. (Mining and Metallurgy, 1941, vol. 22, Aug., pp. 405–409, 412). The author describes some of the beneficiation processes carried out at the Mesabi Range iron mines on the ores which are high in silica. The ratio of beneficiated ore to total ore shipped is steadily increasing. In 1940, 52.5% of all ore shipped was beneficiated in some manner,

and 18.8% of the total was concentrated.

Ferromanganese-Grade Concentrates from the Cuyuna Range. S. M. Shelton and M. M. Fine. (United States Bureau of Mines, 1941, Report of Investigations No. 3582). The authors report on an investigation of suitable methods of preparing concentrates from the manganese ore of the Cuyuna Range of Minnesota, which contain an estimated reserve of 40–50 million tons. Laboratory tests on ore samples treated by jigging, tabling, flotation, and magnetising roasting and separation, showed that manganese concentrates meeting analytical specifications for ferromanganese-grade ore could be obtained. Small-scale pilot-plant operations confirmed the laboratory results.

Sintering of Iron Ore. E. W. Shallock. (Iron and Steel Engineer, 1941, vol. 18, Aug., pp. 59–62). The author discusses the development of sintering practice. He quotes data from a German investigation which show the advantages gained by sintering low-grade ores in that country. Some particulars are also given of a very large sintering plant now under construction in the United States which is designed to produce 4000 tons of sinter per day; it will have about 7500 ft. of belt conveyors, and a total of 6500 h.p. will be required to drive it and the crushing plant. Reference is made to plants

which make a sinter from a mixture of ore, mill scale and blast-furnace flue dust; this sinter is for charging into open-hearth furnaces, and can be used with advantage in place of soft ores.

Design and Operation of the Greenawalt Sintering Plant at the Julienhütte. C. Schrupp. (Stahl und Eisen, 1941, vol. 61, Aug. 21, pp. 785—791). The author describes a large sintering plant at the Julienhütte of the Vereinigte Oberschlesische Hüttenwerke, A.-G., for treating iron-ore fines; the extensions to this plant were completed in 1938, and it now produces 20,000 tons of sinter per month. The technical and economic aspects of the plant and the effect of the sinter produced on the working of the blast-furnaces are discussed. The possibilities of producing a self-fluxing sinter by sintering limestone or dolomite together with the ore are considered.

A New Design of Sintering Machine. (Blast Furnace and Steel Plant, 1941, vol. 29, July, pp. 716–717, 725). An illustrated description is given of an improved design of sintering machine known as the "Agnew." In this machine the moving grate is made up of a large number of castings called "pallets." These are simple castings requiring no machining except a little surface grinding. Each pallet is cast with two parallel rows of recesses or racks. The moving roller track consists of channels in which are mounted roller bearing-wheels, the pitch of the wheels being such that they engage in the rack of the pallet. The track is driven by twin sprockets mounted on a driving shaft connected to a motor through a reduction unit. The chief advantages claimed for the machine are simplicity and low cost.

The Arrangement and Operation of a Pan Sintering Plant, Type GHH-AIB. R. Hahn. (Stahl und Eisen, 1941, vol. 61, July 3, pp. 654–658). The author describes, with drawings and illustrations, the layout and operation of a 12-pan suction-type sintering plant recently erected at a German ironworks. Data on the results achieved are presented and discussed. The plant was built by Gutehoffnungshütte (GHH) under licence from Allmänna Ingeniörs-Byrån (AIB) of Stockholm.

REFRACTORY MATERIALS

(Continued from pp. 1 A-4 A)

Refractory Materials Containing Chrome Ore. K. Konopicky. (Iron and Steel Institute, 1941, Translation Series, No. 35). An English translation is presented of a paper which appeared in Stahl und Eisen, 1941, vol. 61, Jan. 16, pp. 53–63. (See Journ. I. and S.I., 1941, No. I., p. 199 A).

Secondary Expansion of High-Alumina Refractories. J. L. Hall. (Journal of the American Ceramic Society, 1941, vol. 24, Nov., pp. 349-356). The author investigated the secondary expansion.

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sion (or "after-expansion") of several mixtures of raw and calcined diaspore and bauxite with raw and calcined fireclays which had been prepared and fired at 2700° F. The specimens were refired at higher temperatures, and the linear changes were determined. It was found that bodies composed of high-alumina grog and fireclay expanded on refiring, whereas specimens of fireclay grog bonded with ground raw diaspore exhibited shrinkage. The possible causes of

this secondary expansion and shrinkage are discussed.

Use of Carbon and Graphite Improves Operations and Maintenance. F. J. Vosburgh. (Steel, 1941, vol. 109, Sept. 15, pp. 66–68, 176–179). The author describes briefly the process of preparing carbon and graphite for industrial purposes and how electrodes, split carbon ingot moulds and refractory carbon blocks of various shapes are made. A table is presented in which the physical, thermal and electrical properties of carbon, graphite and a number of proprietary brands of graphite are compared. Some advantages of using carbon and graphite ingot moulds (which are made for ingots up to $10 \times 10 \times 30$ in.) are discussed, and reference is made to such applications as the linings of blast-furnace hearths, carbon towers for precipitators built of blocks $8 \times 8 \times 120$ in., and graphite heat exchangers where the conditions would be highly corrosive to steel.

Insulation in High-Temperature Furnace Construction. C. S. Darling. (Mechanical World and Engineering Record, 1941, vol. 110, Oct. 24, pp. 279–280, 283). Some advantages of using insulating bricks on the outside of industrial furnaces are discussed and some calculations showing the decrease in the heat-loss rate after

applying insulation are presented.

FUEL

(Continued from pp. 4 A-6 A)

Fundamental Concepts and Diagrams in Thermodynamics. O. Martin. (Stahl und Eisen, 1941, vol. 61, July 24, pp. 705–713). An exposition of the fundamental laws of thermodynamics with a non-mathematical explanation of entropy. Means of evaluating the absolute entropy are explained. All the fundamental ideas of importance for heat problems may be referred to the temperature-

entropy diagram.

Premixed Combustion of Gaseous Fuel for Steel Finishing Operations. E. B. Dunkak. (Iron and Steel Engineer, 1941, vol. 18, Sept., pp. 69–75). The author describes the construction of units for mixing gaseous fuels and air, these units being entirely independent of the burners. In some cases one mixing unit is in a fuel-supply system supplying a number of furnaces. After describing how the unit functions, some of its advantages and industrial applications are discussed. The development of independent pre-

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mixing equipment has greatly assisted the development of gas immersion heating for tin baths for tinplating and lead baths for

patenting wire.

New Power-House at Carrie Furnace. (Iron and Steel Engineer, 1941, vol. 18, Sept., pp. 104–109). An illustrated description is given of a new power-station recently completed at the Homestead Works of the Carnegie-Illinois Steel Corporation. The steam generating unit is designed to produce 450,000 lb. of steam per hr., and it operates at 585 lb. per sq. in. and at 750° F. The new turbogenerator unit is rated at 40,000 kVA., 13,800 V., 25 cycles, and it

runs at 1500 r.p.m.

Fuels and Furnaces for the Heat Treatment of Steel Castings. T. R. Walker and F. Smith. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 65, Nov. 6, pp. 297–299, 306; Nov. 13, pp. 313–315). In the first part of this paper the authors discuss the characteristics of the following fuels and their suitability for heat-treatment furnaces: (a) Town gas; (b) coke-oven gas; (c) water-gas; (d) raw and clean producer gas; (e) blast-furnace gas; (f) liquid fuels; and (g) solid fuels. In the second part the authors consider factors affecting the choice of fuel and describe a number of large, medium and small furnaces for heat-treating castings. A description is also given of a semi-portable gas producer burning coke, which can be used to replace town gas or other gaseous fuel supply at short notice.

Invention of the "Ono" System Coke Furnaces and its Features. H. Ono. (Tetsu to Hagane, 1941, vol. 27, July, pp. 486–493). (In Japanese). The author describes the development since 1918 of the "Kuroda" coke-ovens in Japan and an improved design of coke-oven battery by the present author to which the name "Ono System" has been given. Improvements in the efficiency of the regenerator and easily controlled heating temperatures are among the advantages

claimed for the Ono system.

Sulphur Recovery from Gas. (Coke and Smokeless Fuel Age, 1941, vol. 3, Aug., pp. 173–174; Sept., pp. 208–210; Oct., pp. 236–238). Several methods for the removal and recovery of sulphur from industrial gases are described. These include the oxide process operated by Ruhrgas A.-G. and the active carbon process developed by the I. G. Farbenindustrie in conjunction with ammonia

synthesis; these are both dry processes.

Particulars are also given of a number of wet methods, among them being the Thylox, Ferrox, Seaboard, Katasulf, Girdler and Girbotol processes, the old and new methods developed by the Gesellschaft für Kohlentechnik and the Alkazid process at the I. G. Farbenindustrie plant at Leuna. It is pointed out that processes which work best on high concentrations of hydrogen sulphide are unlikely to find much application in Great Britain. The industry most likely to develop new processes is the coke industry, particularly in the event of greater use of coke-oven gas.

Improvement of Health Conditions of Labour in Crystallisation Departments of Tar-Distillation Plants. S. S. Naumov. (Iron and Steel Institute, 1941, Translation Series, No. 30). An English translation of a paper which appeared in Reports of the Kharkova Institute of Scientific Research for the Protection of Labour, 1938, No. 8, pp. 5–13.

Gas-Producer Plant and Practice. L. Bailly. (Journal of the Birmingham Metallurgical Society, 1941, vol. 21, Sept., pp. 191-

196). See Journ. I. and S.I., 1941, No. II., p. 66 A.

The Gasification of West-German Bituminous Coal. E. Russ. (Stahl und Eisen, 1941, vol. 61, July 17, pp. 695–698; July 24, pp. 713–717). The author describes and illustrates several types of gas producers, and presents and discusses data relating to coal consumption and gas production for many different West-German coals and anthracites.

PRODUCTION OF IRON

(Continued from pp. 6 A-8 A)

Blast-Furnace Blower Plant in the United States. (Engineering 1941, vol. 152, Nov. 14, pp. 387–388). Some particulars are given of one of the latest type of steam-turbine-driven centrifugal blowers for supplying 85,000 cu. ft. of air per min. to an American blast furnace producing 1000 tons of iron per day. The steam conditions for the unit are: pressure 400 lb. per sq. in. and temperature 700° F. The turbine is of the multi-stage impulse type, the steam economy of which is not dependent on small radial clearances.

Automatic System Conditions Blast Furnace Air. (Blast Furnace and Steel Plant, 1941, vol. 29, Sept., pp. 1015–1016). A brief description is given of a plant designed to remove both water vapour and dirt from blast air and to maintain the moisture content and temperature of the air passing to the blowing engines at predetermined values. (See Journ. I. and S.I., 1941, No. II., p. 194 A).

Benefits Derived from High Blast Temperatures in Blast-Furnace Operation. P. F. Dolan. (American Iron and Steel Institute: Industrial Heating, 1941, vol. 8, July, pp. 746–750). The author reviews some earlier papers on the effect of increasing the temperature of the blast on blast-furnace operation, particularly that of Hoffman (see Journ. I. and S.I., 1940, No. II., p. 178 A), and points out some additional advantages of this practice, including the fact that conditions are created which permit the sulphur to pass from the iron into slag of minimum basicity.

The Smelting of Iron Ores by Old and New Methods. R. Durrer. (Iron and Steel Institute, 1941, Translation Series, No. 33). An English translation of an article which appeared in Stahl und Eisen,

1940, vol. 60, Oct. 3, pp. 877-880. (See Journ. I. and S.I., 1941,

No. II., p. 38 A).

An Investigation of the Reducibility of Lake and Bog Ores in Comparison with that of Hematite and Magnetite Ore. J. Petrén. (Iron and Steel Institute, 1941, Translation Series, No. 32). An English translation of an article which appeared in Jernkontorets Annaler, 1940, vol. 124, pp. 589–599. (See Journ I. and S.I., 1941, No. I., p. 147 A).

The Physical Behaviour of Ores and Additions in the Blast-Furnace. F. Hartmann. (Iron and Steel Institute, 1941, Translation Series, No. 38). An English translation of a paper which appeared in Stahl und Eisen, 1940, vol. 60, Nov. 14, pp. 1021–

1026. (See Journ. I. and S.I., 1941, No. I., p. 201 A).

Effect of Sizes of Material on Blast Furnace Operation. C. C. Furnas. (Blast Furnace and Steel Plant, 1941, vol. 29, June, pp. 625–630, 668, 669). The author reviews the literature on the effects of the sequence of charging ore and coke, and of the lump size of ore, coke and limestone on blast-furnace operation. His general conclusion with regard to American practice is that the optimum size of ore is $\frac{1}{8}$ –1 in., of limestone 1–3 in. and of coke 2–4 in., and the manner of charging these materials should be planned so as to prevent as far as possible segregation of different sizes in the furnace.

The Question of Running Blast-Furnaces on Iron Coke. K. V. Messerle and G. S. Gerasimchuk. (Iron and Steel Institute, 1941, Translation Series, No. 28). An English translation of an article which appeared in Metallurg, 1939, No. 10–11, pp. 21–27. (See

Journ. I. and S.I., 1941, No. I., p. 43 A).

British Standard Specification for Portland Blast Furnace Cement (Not Exceeding 65% Blast Furnace Slag. (British Standard Institution, No. 146, 1941). This Standard, which was last revised in 1932, has been revised once more in order to introduce into it the modifications which were recently incorporated in the revision of

British Standard No. 12 for Portland Cement.

Characteristics of the Rotary Furnace Raw Iron. S. Yanagida. (Tetsu to Hagane, 1941, vol. 27, July, pp. 455–462). (In Japanese). In the preparation of granulated iron in a rotary furnace for steel-making the author distinguishes between lumps (German Luppe), sponge iron and an intermediate product which he calls pumice iron. In the present paper he discusses the properties of these three products.

Iron Powder—Some Notes on Its Production, Use and Future Prospects. A. H. Allen. (Steel, 1941, vol. 109, Oct. 6, pp. 58–59, 90, 91). The author briefly reviews several methods of producing iron powder direct from ore and indirectly from sponge iron, and discusses the application of products made from iron powders of

different degrees of purity.

FOUNDRY PRACTICE

(Continued from pp. 8 A-10 A)

Recent Foundry Developments Reviewed. V. C. Faulkner. (Institute of British Foundrymen, 1941, vol. 65, Oct. 30, pp. 281–282). In this review of modern trends and developments in the foundry, the author refers to research in America on methods of testing sands, the success in America of the introduction of hot blast in cupola practice, the reclamation of swarf, treating molten iron in the ladle, production of pressure die castings, and the hydro-blast

system of cleaning castings.

Economy and Salvage in the Foundry. D. Carrick. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 65, Oct. 23, pp. 267–269). The author gives numerous examples of practical methods of reducing costs and of reclaiming materials used in foundry processes. These include: (a) Regular checking for accuracy of all weigh scales at the cupola and in cleaning departments; (b) reducing the weight of gates and sprues; (c) orderly collection of spilled metal; (d) economy in the use of paraffin for cleaning; (e) recovery of core sand; (f) efficient utilisation of labour; (g) organisation of a system of promptly reporting and repairing leaks in compressed air lines; and (h) more attention to be paid to efficient lighting.

Pig-Iron Conservation. (Canadian Metals and Metallurgical Industries, 1941, vol. 4, Sept., pp. 230–231, 234). Some suggestions contained in a report from the Ore Dressing and Metallurgical Laboratories, Bureau of Mines, Ottawa, on methods of dealing with the shortage of pig iron in Canadian foundries are presented. The methods relate to the classification and selection of scrap and the technique to be adopted when increasing the proportion of scrap

iron in the cupola charge.

The Application of High-Frequency Furnaces in the Iron Foundry. C. W. Pfannenschmidt. (Giesserei, 1940, vol. 27, Sept. 6, pp. 341–346). The author discusses experience gained in the course of nearly two years' operation of a 1½-ton high-frequency furnace, during which about 4500 melts of grey iron were produced. Technical data on the economy of the furnace are presented and a comparison is made of the costs of working small electric-arc and high-frequency furnaces. The advantages of the latter type of furnace include: (1) There are no electrodes; (2) the refractory lining is inexpensive and the labour charge for putting it in is low; (3) operation is simple and cheap; and (4) current consumption is low.

Cast Engine Parts. (Automobile Engineer, 1941, vol. 31, Nov. 6, pp. 379–382). An illustrated description is given of the methods by which the Ford Motor Co., Ltd., produces cast engine parts such as crankshafts, camshafts, valve-seat inserts, valves and push-rods.

The chemical analyses of the alloys and details of the heat treatment

are given.

The Pattern and Its Influence on Foundry Economy. C. Wagner. (Giesserei, 1940, vol. 27, Oct. 4, pp. 377–383). The author discusses the design of patterns, the technique of pattern-making and the manner in which these two factors affect the economy of a foundry. Practical examples taken from many years' experience of foundry work are cited.

Investigation of the Influence of Mould Friction on Tearing in Castings. J. H. Andrew and H. T. Protheroe. (Iron and Steel Institute, 1942, this Journal, Section I.). The "bulk" resistance of sand to the contraction of steel has more effect on the tearing of steel castings than the friction between contracting steel and the actual sand grains. Long steel bars were cast in various grades of sand in a series of boxes, which enabled different volumes of each grade of sand to be employed. The degree of tearing varied with varying bulks of sand, being more severe as the bulk of sand surrounding the casting was increased, but castings rammed in coarse sand did not tear any more severely than castings made in fine sand. By using sloping runners, the slight ease given to the contracting casting against the bulk resistance of the sand was sufficient to prevent tearing.

An attempt to obtain the temperature at which the castings

cracked is briefly described.

Gas for Drying Moulds and Cores by Modern Methods. W. Callenberg. (Giesserei, 1940, vol. 27, Oct. 18, pp. 397–405; Nov. 1, pp. 421–423). The author reviews progress made in the design of stoves for drying moulds and cores. He compares the efficiency and cost of core-drying with stoves heated by oil, gas, electricity, steam and hot water, and describes and illustrates several types of modern gas-heated drying installations.

Jacketed Cylinder Castings for Pulping Machines. E. Longden. (Iron and Steel, 1941, vol. 15, Oct., pp. 12–14, 19). The author gives a detailed description of the moulding technique successfully employed for making hollow cast-iron jackets, weighing about 2 tons, which surround the cylinders of pulping machines used in artificial

silk manufacture.

Linked-Plate Conveyors for Foundries. H. Schulze-Manitius. (Giesserei, 1940, vol. 27, Nov. 1, pp. 417–421). The author describes and illustrates different types of continuous linked-plate conveyors as used in foundries. This form of transport has proved very efficient in foundries, because it is particularly suitable for carrying heavy moulding boxes, and the lower part of the conveyor can be used to carry the empty boxes back to the moulding shop.

PRODUCTION OF STEEL

(Continued from pp. 11 A-14 A)

Steel and the Engineer. (Automobile Engineer, 1941, vol. 31, Nov. 6, pp. 374–378). A survey is presented of the methods of making and processing steel, and reference is made to defects which can be detected in the ingot stage, during rolling and pickling, and

in application.

Jones & Laughlin Steel Corporation in the Service of the Country for almost a Century. C. Longenecker. (Blast Furnace and Steel Plant, 1941, vol. 29, Aug., pp. 858—893). A very comprehensive and profusely illustrated account is presented of the development and present plant and processes at the iron and steel works of the

Jones & Laughlin Steel Corporation at Pittsburgh.

British Standard Test Code for Open-Hearth Melting Furnaces for the Refining of Steel. (British Standard Institution, No. 979–1941). This Code has been prepared to provide an agreed standard testing procedure for evaluating the performance and efficiency of openhearth furnaces for the refining of steel. It is in two parts. In Part I. a short, simple code is given for carrying out, at a minimum cost, simplified industrial tests for evaluating the performance of furnaces as effective and economic units.

Part II. comprises a comprehensive code for the complete evalua-

tion of the performance and efficiency of furnaces.

Gas-Fired Open Hearth Furnaces. G. M. Parker. (Proceedings of the Natural Gas Section of the American Gas Association, 1941, Annual Meeting, pp. 238–240). The author describes and discusses a design of open-hearth furnace suitable for firing with natural gas alone or with oil and natural gas. In this furnace the slope of the port which determines the angle at which the gases are directed on to the bath is not so pronounced, and the oil-burner is situated above the gas-burner.

The Production of Mild Steels in the Acid Open-Hearth Furnace with Particular Consideration of the Melting Practice. F. Eisermann. (Iron and Steel Institute, 1941, Translation Series, No. 39). An English translation of a paper which appeared in Stahl und Eisen, 1940, vol. 60, July 18, pp. 629-634. (See Journ. I. and S.I., 1941,

No. II., p. 74 A).

The Use of Chromium in the Production of Steel. Part I.—The Oxidation Loss of Chromium in the Basic Open-Hearth Furnace. M. Hauck. Part II.—The Bahaviour of Chromium in the Basic Open-Hearth Furnace. G. Rockrohr. (Iron and Steel Institute, 1941, Translation Series, No. 37). An English translation of an article which appeared in Stahl und Eisen, 1941, vol. 61, Feb. 27, pp. 201–210. (See Journ. I. and S.I., 1941, No. II., p. 5 A).

The Manufacture of High Quality Low Cost Steel. P. J. McKimm. (Steel, 1941, vol. 109, Sept. 29, pp. 78–82, 90). The author describes open-hearth furnace practice for making steels with up to 0.10% of carbon, with particular reference to the effects of charge composition and order of charging on the quality of the steel

produced.

Top Charging Open Hearth Furnaces is Economically Attractive. J. O. Griggs. (Blast Furnace and Steel Plant, 1941, vol. 29, Sept., pp. 1002–1004). The author outlines a scheme for an open-hearth furnace with a hinged roof designed for top-charging. The object of this is to enable the furnace to be charged much more rapidly by means of large drop-bottom scrap-boxes. Other advantages claimed are elimination of a large number of charging-boxes and charging-box cars and their maintenance, reduction in size of the stock-house and a reduction in the number of doors in the furnace to one which would be used for working the heats with ore and limestone. The author estimates that this method of charging would result in a saving of 65 cents per ton of ingots produced.

Bibliography on the Physical Chemistry of the Open-Hearth Process. (Covering the Period 1938 to 1940). (Iron and Steel Institute, 1941, Bibliographical Series, No. 8 A). This bibliography is a continuation of No. 8 with the same title which covered the

period 1920 to 1937.

Lead-Bearing Steels. L. Guillet. (Iron and Steel Institute, 1941, Translation, No. 25). An English translation of a paper which appeared in Revue de Métallurgie, Mémoires, 1940, vol. 37, Feb.,

pp. 29-36. (See Journ. I. and S.I., 1940, No. II., p. 12 A).

Steel-Making Electric Furnaces of the United States. T. J. Ess. (Iron and Steel Engineer, 1941, vol. 18, Oct., pp. 65–67). The author points out the phenomenal increase in the production of steel in electric furnaces in the United States, and presents a table in which the number of furnaces installed or under construction in August 1941 are shown separately for each company, together with the principal dimensions, capacity, type, transformer capacity and estimated annual output.

The Most Suitable Lay-Out of Arc-Furnace Steel Melting-Shops. H. Müller. (Stahl und Eisen, 1941, vol. 61, July 17, pp. 685–694). The author discusses the design and lay-out of steelworks meltingshops for electric-arc furnaces, with special reference to means and space for removing the furnace cover, charging, tilting the furnace, and the removal of furnace gases. Diagrams of several types of tilting furnaces and hoods for the removal of gases are given and their advantages, disadvantages and cost are considered.

A Method of Melting Steel in a Basic Electric-Arc Furnace. K. Matsuyama, T. Iki and K. Muramoto. (Iron and Steel Institute, 1941, Translation Series, No. 27). An English translation of a paper which appeared in Tetsu to Hagane, 1940, vol. 26, Aug. 25, pp.

597-608. (See Journ. I. and S.I., 1941, No. I., p. 92 A).

Voltage Control of Furnace Transformers. J. Fowler. (Metropolitan-Vickers Gazette, 1941, vol. 19, Oct., pp. 203–207). The author describes the construction of tapping switches for controlling the voltage of the current supplies from transformers to electric furnaces.

An Investigation of Over Voltages Associated with Arc Furnace Operation. L. V. Black and E. W. Boehne. (Iron and Steel Engineer, 1941, vol. 18, Sept., pp. 88–94). The authors report on an investigation of over-voltages associated with the switching of the power supply to a 25-ton electric-arc furnace at the works of the Bethlehem Steel Co. Surge voltage records and magnetic oscillograms, taken with and without protection equipment, are presented. The investigation revealed that: (a) No surges were produced by interrupting overload currents; (b) surges were only produced by interrupting lighter currents; (c) both lightning arrestors and capacitors were found suitable as a means of lowering the magnitude of the surges produced; (d) capacitors connected line to earth were found to be more effective than capacitors line to line; and (e) capacitors line to earth were installed to overcome the difficulty at the Bethlehem plant.

Fundamental Considerations in Supplying Power to Arc Furnaces. F. M. Starr and O. B. Falls. (Iron and Steel Engineer, 1941, vol. 18, Oct., pp. 30–42). The authors consider the principles involved in the design of an electric-power distribution system to supply adequately the loads of arc furnaces as well as means of preventing furnace load fluctuations from causing fluctuations in lighting

circuits.

Surge Voltage Tests on Electric Arc Furnaces. Z. R. White-house and C. C. Levy. (Iron and Steel Engineer, 1941, vol. 18, Oct., pp. 51–59). The authors record some test data obtained on the magnitude of the voltage surges which occur in the operation of electric-arc steel furnaces and their frequency. Their occurrence is related to the switching and the melting process and methods of

reducing the surges are explained.

Tests with the Rohn Low-Frequency Furnace. A. Niedenthal and H. Wentrup. (Stahl und Eisen, 1941, vol. 61, June 5, pp. 557–566; June 12, pp. 588–591). The authors give a full account of an investigation of the refining of pig iron in a 1½-ton Rohn low-frequency furnace. It was fully established that the reactions in the furnace between the bath and the addition materials such as ores and slag take place at a high velocity; the reason for this is not only the intimate mixing of the contents of the bath, but also the penetration of heat through the non-metallic materials. This heat effect is so great that even high-melting-point slags such as high-silica slags and highly basic slags, attain a sufficiently low viscosity to become very reactive. The movement of the bath brings the metal more into contact with the air, and it is therefore more liable to take up nitrogen than is the case in other types of furnace.

In certain cases, such as the production of nitrogen-rich chromium steel or chromium-nickel steel, this is an advantage. In other instances the absorption of nitrogen can be counteracted by a vigorous boil. When adding aluminium, silicon or other agents to reduce the slag, care must be taken to see that these elements only react with the slag and do not form alloys with the melt. The rapid movement of the bath can cause the slag to react with the furnace lining. Whilst it is true that the formation of a depression in the centre of the bath means that there is little movement of the outer rim of metal against the lining, the metal between the poles moves all the more rapidly in consequence, and can thus cause erosion of the lining near the poles; it is therefore essential to see that the composition of the slag is such that it is unable, or almost unable, to dissolve the lining material. The tests with a silica-saturated slag and an acid lining showed that the lining can be eroded by a purely The short life of the lining because of this mechanical wear. mechanical wear is the reason why this type of furnace cannot yet be used for steelmaking, and the future development of the furnace is closely linked with the lining problem. The industrial application of the Rohn furnace will also depend on whether the duration of the treatment in the furnace can be shortened by increasing the power supply without at the same time causing a still more rapid movement of the bath.

Alloy Steel Manufacture in Australia. H. Stephenson. (B.H.P. Review, 1941, vol. 18, Sept., pp. 6–8). The author describes some of the difficulties encountered in the manufacture of alloy steels, including tool steels and stainless steels, at the works of the Commonwealth Steel Co., Ltd., where a 5-cwt. and a 1-ton high-frequency furnace have recently been added to the existing furnaces.

Monongahela River—Steel Plant Water Supply. J. C. Jamison and J. M. Harvey. (Blast Furnace and Steel Plant, 1941, vol. 29, Sept., pp. 989–1001). The authors consider the characteristics of the Monongahela River water, how these affect its industrial applications and how it is treated for use as cooling water and boiler feed-

water at the steelworks of the Pittsburgh district.

Filters and Strainers for the Steel Industry. G. P. Dempler. (Iron and Steel Engineer, 1941, vol. 18, Oct., pp. 25–29). The author describes some different types of pressure filters for steelworks water systems for descaling, for cooling rolls, for lubricating

systems, fuel systems and miscellaneous services.

Analytical Investigation of Basic Open-Hearth Slags. E. Diepschlag. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Mar., pp. 421–426). The author has investigated the composition of basic open-hearth slags by making determinations of the amounts of free lime and free ferrous oxide. This was done with slags from melts in 40-ton and 120-ton furnaces. The proportions of free lime in the solid and liquid phases and that of fixed lime were determined, and it was established that a large proportion of the lime was free

in solution, and that in the smaller furnace a small amount of free

lime was also present in the solid phase.

Slag Systems. R. Hay and J. White. (Journal of the West of Scotland Iron and Steel Institute, 1940-41, vol. 48, Part VI., pp. 75-81). The authors refer to a previous investigation of the CaO-Fe₂O₃-Fe system (see Journ. I. and S.I., 1940, No. II., p. 211 A) and give an account of some recent exploratory investigations of the influence of magnesia on lime/iron-oxide systems. Owing to the complexity introduced by the dissociation of Fe₂O₃, melts containing more than 60% of this oxide were not employed in the present series of experiments. The authors make the following deductions from the CaO-Fe₂O₂-MgO diagram which they developed: (1) Materials which have a composition within the field CaO-MgO-Fe-2CaO.Fe₂O₃ will, in general, have a high melting point, but will be very prone to disintegrate during storage due to hydration of the free CaO; (2) dolomite is essentially a mixture of CaO and MgO and complete stabilisation can only be obtained if all the CaO is combined—in this system, by the formation of dicalcium ferrite: (3) all the CaO must be combined before any of the MgO is attacked; (4) the disadvantage of the presence of much 2CaO.Fe₂O₂ lies in its low melting point, which is 1436° C.; this will be lowered in the presence of MgO with which substance it must form a eutectiferous series; furthermore, as the Fe₂O₃ content is raised still further CaO.Fe₂O₃ (melting point 1216° C.) will appear with a still further drop in refractoriness; (5) the action of Fe₂O₃ on MgO is to form MgO.Fe₂O₃ which, even though it contains 80% of Fe₂O₃, has a melting point of over 1700° C.; in addition, it can take ${\rm Fe_3O_4}$ into solid solution without a marked drop in melting point.

The Rôle of the Ingot Mould in Control of Semi-Finished Surface on Killed Steels. H. J. Forsyth. (Blast Furnace and Steel Plant, 1941, vol. 29, June, pp. 609–617). The author gives an account of his investigations of the effect of new and old ingot moulds and their treatment on the surface condition of billets rolled from the ingots. He points out that billets from coated moulds showed an increase in the surface defects the longer the mould was used, whilst ingots from uncoated moulds behaved in the opposite manner. Old moulds coated with tar or pitch at low temperatures showed only a slight advantage over uncoated moulds with respect to the subsequent surface condition of the billet, but if the old moulds were coated at a temperature in the 400–500° F. range a very much better surface condition of the billet was obtained. The relation of mould

life to soaking-pit practice is discussed.

Material for Steelworks' Ingot Moulds. K. Hoffmann. (Stahl und Eisen, 1941, vol. 61, June 19, pp. 606–609). The author considers some of the factors affecting the life of ingot moulds, particularly the foundry technique in the making of moulds and such items as uneven wall thickness, defects on the inside surface, means of reducing contraction stresses and teeming temperatures. Some

data on the changes in hardness and composition of moulds after

frequent use are presented.

Design and Operation of Ingot Strippers. H. W. Ball. (Steel, 1941, vol. 109, Oct. 6, pp. 80–82). The author describes the construction and operation of ingot strippers for both wide-end-up and wide-end-down moulds.

Measures of Works Economics for Increasing the Capacity of the Iron and Steel Industry. R. Risser and W. Schütte. (Iron and Steel Institute, 1941, Translation Series, No. 41). An English translation of a paper which appeared in Stahl und Eisen, 1940, vol. 60, Nov. 28, pp. 1069–1075; Dec. 5, pp. 1107–1113. (See Journ. I. and S.I., 1914, No. I., p. 206 A and 1941, No. II., p. 164 A).

FORGING, STAMPING AND DRAWING

(Continued from pp. 14 A-16 A)

Dies and Tools for Forging Presses. W. Naujoks. (Industrial Heating, 1941, vol. 8, July, pp. 726–732; Aug., pp. 846–848). The author discusses the characteristics of die steels, the methods of machining the die contours and the testing of dies and die trimmers.

Modern Shell Forging Methods. F. G. Schranz. (Metals and Alloys, 1941, vol. 14, Sept., pp. 301–309). The author presents an illustrated review of various methods employed in the United States for making shell forgings. Various types of hydraulic piercing and drawing presses, mechanical upsetters and roller drawing benches are used.

New Shell Forging System. (Steel, 1941, vol. 109, Sept. 22, pp. 50–51, 83). An illustrated description is given of a large forging machine designed for the automatic continuous production of 240–300 90-mm. shells per hr. from hot steel billets. The machine incorporates a rotary indexing die-table, self-aligning punches and a mandrel with automatic stripping, combination roller and ring-dies for final drawing of the shell, automatic cooling of the punches and mandrel between each operation, and an automatic lubrication

system for dies and punches containing colloidal graphite.

Shell Forging by the Pierce and Draw Method. M. S. Evans. (Iron Age, 1941, vol. 148, Oct. 2, pp. 27–31). The author describes the sequence of processes in the manufacture of 9·2-in. shell forgings from blooms 8 ft. long \times 8½ in. square. The long bloom is nicked and broken into 20-in. lengths, which are heated to 2125–2175° F. and pierced in a 1000-ton press to a cup $10\frac{3}{4}$ in. outside dia., $7\frac{5}{16}$ in. inside dia., $23\frac{3}{4}$ in. long. The cup then passes to a 260-ton drawing press, which reduces it to a shell forging $9\frac{11}{16}$ in. outside dia., $7\frac{5}{16}$ in. inside dia., $35\frac{1}{8}$ in. long. The rate of production is 40 forgings per hr.

Here is How a Small Plant Forges 81-mm. Mortar Shells. C. C. Barrenbrugge. (Iron Age, 1941, vol. 148, Oct. 18, pp. 35–37). The author describes how an old 5-in. forging machine was adapted so that it could be used to manufacture $3\frac{3}{16}$ -in.-dia. trench mortar bombs from $1\frac{3}{4}$ -in.-dia. stock bars in seven passes. A production

of 80-100 per hr. has been achieved.

Forging Shells by the Witter Process. S. F. Keener. (Heat Treating and Forging, 1941, vol. 27, Aug., pp. 379–380). Rapid Production of Shell Forgings by the Witter Process. (Industrial Heating, 1941, vol. 8, Aug., pp. 833–836, 840). The author describes the Witter process of making shells. This is really a modification of the Assel cross-roll tube mill. (See Journ. I. and S.I., 1941, No. II., p. 174 A).

British Standard Specification for Carbon Steel Forgings for Ship and Marine Engine Purposes. (British Standards Institution, No. 29, 1941). The present Specification constitutes a revision of British Standard No. 29, originally issued in 1907 and last revised

in 1909.

ROLLING-MILL PRACTICE

(Continued from pp. 16 A-18 A)

Precipitrons for the Steel Industry. G. E. Stoltz. (Iron and Steel Engineer, 1941, vol. 18, Sept., pp. 78–80). The author discusses the use of electric dust precipitators for cleaning the air

supply for cooling mill motors.

Specific Pressures and Spreading in the Hot-Rolling of Steels EYa-1 and U-8-A as Compared with Low-Carbon Steel (1010). N. I. Svede-Shvets. (Iron and Steel Institute, 1941, Translation Series, No. 31). An English translation of a paper which appeared in Metallurg, 1939, No. 7, pp. 82–89. (See Journ. I. and S.I., 1940, No. I., p. 140 A).

Contribution to the Calculation of Rolling Pressure and Rolling Work. K. Láng. (Iron and Steel Institute, 1941, Translation Series, No. 34). An English translation of a paper which appeared in Stahl und Eisen, 1916, vol. 36, Jan. 6, pp. 10–17. (See Journ. I.

and S.I., 1916, No. I., p. 354).

Rolls and Roll Design. C. Elms. (Iron and Steel Engineer, 1941, vol. 18, Oct., pp. 68–71). The author discusses roll design for the rolling of angles, beams and bars, and explains the Lennox method of calculating the position of the pitch-line and determining

the pitch diameter.

Calibration which Takes into Account Elastic Deformations and Their Experimental Investigation. Yu. M. Faynberg. (Iron and Steel Institute, 1941, Translation Series, No. 29). An English translation of an article which appeared in Metallurg, 1939, No. 10–11, pp. 141–148. (See Journ. I. and S.I., 1941, No. I., p. 50 A).

Progress in the Direct Rolling of Metal. (Iron and Steel, 1941, vol. 15, Oct., pp. 3-7; Nov., pp. 40-43). Difficulties experienced in the direct rolling of metal are discussed with particular reference to Russian investigations and to the results achieved at the Hammer and Sickle Works, where a mill was put in commission in 1939. This mill was designed for the direct rolling of steel strip 300-600 mm. wide and up to 10 mm. thick. Particulars are given of the equipment of this mill, including the ladles, pouring boxes, water-cooled rolls, guards and instruments for measuring roll pressures.

Investigating and Increasing the Capacity of a Cogging Mill. H. Euler. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Mar., pp. 465-472). The author gives an account of the application of time-study methods to a cogging mill with the object of increasing

its efficiency.

The Rolling of Beams and Channels with Common Roughing Rolls. C. Holzweiler. (Stahl und Eisen, 1941, vol. 61, June 26, pp. 617-624). The author describes, with the aid of numerous diagrams and tables, the calibration of roughing rolls which can be used for both beams and channels of certain German standard dimensions.

The Conversion of a Rolling Mill for High-Quality Steel. A. Fischnich. (Stahl und Eisen, 1941, vol. 61, Aug. 7, pp. 753-756). The author describes the design and lay-out of a German rolling mill which was modernised and extended during the period 1936-1939. This mill includes both roughing and finishing stands, and is designed for rolling small quantities of shapes and sections of

The Rolling of Heavy and Medium Plates. E. Howahr. (Iron and Steel Institute, 1941, Translation Series, No. 36). An English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, Jan. 23, pp. 73-83; Jan. 30, pp. 100-107. (See Journ. I. and S.I., 1941, No. I., p. 211 A).

Process of Cold Rolling. T. C. Mayberry. (Iron and Steel Engineer, 1941, vol. 18, Sept., pp. 98–102). The author describes the production of cold-rolled strip at the Ecorse Works of the Great Lakes Steel Corporation, dealing in turn with continuous pickling, cold reduction in two 3-stand 4-high mills, shearing, box annealing,

skin-pass rolling, finishing and despatching.

Some Operating Problems of Continuous Pipe Mills. L. J. Hess. (Iron and Steel Engineer, 1941, vol. 18, Sept., pp. 110-113). The author discusses the causes of stoppages in the operation of Fretz-Moon tube-mills. Experience has shown that about 80%, of all shut-downs are connected with the flash-welding cycle. The causes may be any of the following: faulty coils which telescope in the coilbox, faulty coil-ends, variations in width and thickness of skelp, dirt or grease picked up by the coils in transit, incorrect setting of the leveller for a change in thickness, and scale or dust causing short circuits on the flash-welder itself.

The Manufacture of Bundy Tubing. (Machinery, 1941, vol. 59, Oct. 23, pp. 85–89). An illustrated account is given of the manufacture of Bundy tubing. In the finished state this tubing consists of two tubes of steel strip wrapped one around the other, with their seams diametrically opposite. The outer strip is of bright mild steel, and the inner strip is of the same material but it is coated with copper on both sides. After the two strips are wrapped together to form the tube the work is passed through an electric furnace, which melts the copper and effectively brazes the inner surface of the outer tube to the outer surface of the inner tube. In a subsequent process the outer surface of the finished tube is tinned. At present the maximum size of tubing made in Britain by this process is $\frac{5}{16}$ in outside dia. The tubing combines good working properties with great strength and high resistance to fatigue, and it is therefore used for petrol feed-pipes on internal-combustion engines.

Electrical "Firsts" at New Cold Strip-Mill. (Iron Age, 1941, vol. 148, Sept. 18, p. 57). Brief particulars are given of the electric drives for the five stands of a new cold strip-mill recently put in operation at the Irvin Works of the Carnegie-Illinois Steel Corpora-

tion.

Cold-Mill Feed-Table Maintains Alignment of Sheets. (Steel, 1941, vol. 109, Sept. 22, pp. 68–71). An illustrated description is given of a roller feed-table for aligning and centring sheets and feeding them to the cold-mill. The revolving guides with tapered flanges and the conveyor belts are mounted in such a way that the entire feed-table can be adjusted easily and quickly to take any width of sheet. The labour costs for handling the sheets are reduced, and sheets with turned-over corners or edges scarcely ever arise when this table is used.

The Sawing of Metals. C. M. Thompson. (Iron and Steel Engineer, 1941, vol. 18, Oct., pp. 72–75). The author discusses some factors affecting the efficient sawing of metals and presents some data on the hot and cold-sawing of billets.

HEAT TREATMENT

(Continued from pp. 19 A-24 A)

The Application of Results of Equilibria Investigations to Furnace Atmospheres to Bright-Annealing and to Annealing without Decarburisation. G. Neumann. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Mar., pp. 429–438). From the data obtained in furnacegas equilibria investigations the author constructs diagrams which show the conditions under which a given atmosphere at elevated temperatures is: (a) itself in a state of equilibrium, (b) in equilibrium

with iron in that it is neither oxidising nor reducing, and (c) in equilibrium with iron-carbon structures in that it is neither carburising nor decarburising. A special constitutional diagram for a protective atmosphere prepared by the partial combustion of long-distance gas is also presented and this shows why this atmosphere is suitable for bright annealing and for annealing without decarburisation.

The Control of Heat-Treatment Furnaces. H. J. Smith. (British Steelmaker, 1941, vol. 7, Nov., pp. 225-227). The author discusses the advantages and limitations of three types of temperature-controlling systems for heat-treatment furnaces; these are known as fixed, floating and proportional position control, respectively. In fixed-position control very little change of temperature is needed for the two-position controller to alter the heating from one rate to the other. With floating-position control the alteration from the minimum to the maximum heating rate is made slowly, usually through a reduction-geared motor operator, and the impulses of a two-position controller may not be sufficiently prolonged to vary the heating rate to its extreme limits. Proportional position control provides an infinite number of heating rates, and it is of zone rather than point character. Reference is made to a new system combining potentiometric high-temperature measurement with pneumatic control of the heating gas supply for heat-treatment furnaces.

The Siliconising of Steel. I. Stewart. (Mechanical World and Engineering Record, 1941, vol. 110, Oct. 17, pp. 274-275). The author describes the process of siliconising steel (frequently called "Ihrigizing"). The silicon-rich case produced contains 8-15% of silicon and possesses corrosion-, oxidation- and wear-resistant properties. The method employed is usually that based on the reactions which take place when chlorine is passed over silicon carbide in the presence of iron or steel. A rotary or retort-type of pack or gascarburising furnace can easily be adapted for siliconising. It should possess a gas-tight muffle with inlet and outlet tubes for the chlorine. The parts are packed in silicon carbide and the temperature is raised to 900-1000° C.; the chlorine need not be admitted to the muffle until this temperature has been reached. Chlorine gas of 90% purity is satisfactory and no dehydration is necessary. It is thought that the chlorine reacts selectively with the carbide and liberates silicon in nascent form, which is then free to diffuse into the steel. There is no known heat treatment for improving the properties of a siliconised case, but heat treatment can be applied to alter the properties of the core. Some data are presented on the physical properties and corrosion and wear resistance of siliconised

Fully Mechanized Handling Now Provided in Electric Salt-Bath Furnaces. (Steel, 1941, vol. 109, Sept. 29, pp. 75–76). A brief description is given of an electrically heated salt-bath furnace for case-hardening small parts. An interesting feature of the furnace

is that the parts are suspended from a horizontal revolving screw over the centre of the bath. As the speed at which the screw turns can be adjusted, the time taken for the part to travel the length of the bath can be predetermined to give the desired period of immersion.

Carburizing Steel with Town Gas. A. S. Fitzpatrick. (Gas Journal, 1941, vol. 236, Nov. 12, pp. 251–253). The author discusses the application of various gases as carburising media, and gives the results of some experiments recently carried out by the National Gas Association of Australia, in which Melbourne town gas as supplied, and after bubbling through petrol, were used to carburise samples of $\frac{1}{4}$ -in. steel plate (carbon 0.12%) for 2- and 4-hr. periods at a temperature of 920-940% C. It appeared that no marked improvement was achieved by the addition of petrol vapour to the gas. It was thought that this particular town gas was too high in carbon dioxide and too low in methane, but case-depths were obtained in a given time comparable with those obtained using natural gas, propane and butane mixtures in the United States.

Carburizing and Case-Hardening. C. R. Day. (Metals Treatment Society of Victoria: Australasian Engineer, 1941, vol. 41, Aug. 7, pp. 15–16a, 30–32b). The author presents a comprehensive account of the theory and practice of carburising and case-hardening

in solid, liquid and gaseous media.

Carburising Boxes. I. Stewart. (Iron and Steel, 1941, vol. 15, Oct., pp. 23–26). The author discusses factors affecting the life of carburising boxes. These include design, composition of the alloy used and soundness of the casting, type of fuel, operating temperature and method of heating and cooling. The author is not in agreement with the theory that large quantities of the compound must be present to obtain satisfactory carburisation, for investigations have shown that a $\frac{1}{2}$ -in. layer round the part is ample to produce case depths up to 0·100 in.

Chrome-Molybdenum Drawing and Forming Dies Flame Hardened. (Heat Treating and Forging, 1941, vol. 27, Aug., p. 391). Some particulars are given of a chromium-molybdenum iron (total carbon 3·30%, molybdenum 0·30% min., chromium 0·50%) which can be flame-hardened without distortion or scaling and is suitable for dies for pressing automobile petrol tanks, refrigerator panels and stove

parts.

Electric Salt-Bath Furnaces for Heat Treating High-Speed Molybdenum Steels. H. L. Edsall and T. E. Lloyd. (Iron Age, 1941, vol. 148, Oct. 2, pp. 39-46). The authors discuss some characteristics of electrically heated salt-bath furnaces for the heat treatment of molybdenum high-speed steels. They explain a system of code letters which many of the American tool-steel manufacturers have agreed to use for their proprietary brands of steel. In conclusion they make recommendations on heating and quenching schedules for this class of steel.

Heat Treatment of Molybdenum High-Speed Steels. (Mechanical Engineering, 1941, vol. 63, Oct., pp. 703–705; Metal Progress, 1941, vol. 40, Sept., pp. 307–310). Some heat-treatment schedules for three types of molybdenum high-speed steel are presented. (See p. 19 A). These were drawn up by a special committee of the

Office of Production Management in the United States.

Salt-Bath Method for Hardening Molybdenum High-Speed Steels. (Mechanical Engineering, 1941, vol. 63, Oct., pp. 705–706; Metal Progress, 1941, vol. 40, Sept., pp. 310–311). Recommendations are made by a special committee appointed by the Office of Production Management in the United States on the use of salt-bath furnaces, heated by immersed electrodes, for the heat treatment of

molybdenum high-speed steels. (See p. 20 A).

New Ideas in a Small-Parts Hardening Furnace. (Automotive Industries, 1941, vol. 85, Aug. 15, pp. 34–35, 62). An illustrated description is given of a small gas-fired furnace for the shallow case-hardening of small automobile parts. The furnace is heated by twenty return-bend radiant tubes. The parts to be hardened are pushed through the furnace on trays which move in two parallel rows, the pusher mechanism being controlled by a time-clock which can be pre-set. An inclined-chain conveyor carries the trays from the discharge end down into an oil-quenching tank and out of it up to an unloading bench.

WELDING AND CUTTING

(Continued from pp. 24 A-27 A)

Welding Metallurgy. Volume II. Parts VII. and VIII. O. H. Henry and G. E. Claussen. (Welding Journal, 1941, vol. 20, Aug., pp. 520–526; Sept. pp. 592–601). In the seventh part of this series (see Journ. I. and S.I., 1941, No. II., p. 208 A) the authors discuss the weldability of austenitic chromium-nickel stainless steels, non-hardenable ferritic chromium irons containing more than 15% of chromium, and the hardenable chromium steels containing less than 16% of chromium. Particular attention is paid to the conditions which promote intergranular carbide precipitation in these stainless steels. In the eighth part the authors explain the theory and practice of stress-relieving heat treatment for welds.

Crack Sensitivity in Welded Chromium-Molybdenum (1% Chromium 0.2% Molybdenum) Steels of Thin Section. J. G. Ball. (Transactions of the Institute of Welding, 1941, vol. 4, Oct., pp. 181–187). The author reviews recent literature on the sensitivity of chromium-molybdenum steels to cracking on or after welding. From the evidence the author deduces that certain factors, such as chemical composition and an active boil of the melt during manufacture, have a greater and more consistent effect on crack sensi-

tivity than others. No test has been reported in which active boiling did not render a particular steel less sensitive, and most of the evidence supports the conclusion that increases in the amounts of carbon, sulphur and phosphorus increase the crack sensitivity.

Reclamation Welding of Manganese Steel Trackwork Units. D. B. Rice. (Welding Engineer, 1941, vol. 26, Sept., pp. 21–24). The author describes the welding technique for repairing manganese steel railway crossings. (This paper also appeared in Iron Age,

1941, vol. 148, Sept. 11, pp. 54–58, see p. 25 A).

Welding Cold Cast Iron. P. Krug. (Giesserei, 1940, vol. 27, Nov. 1, pp. 423–427). The author reports on an investigation of the weldability of cast iron with particular reference to methods of producing a good electrically welded joint without preheating the iron. The effect of coating the faces of the joint with copper, nickel, zinc, lead and aluminium before welding were examined. The best results were obtained after coating with either nickel or copper; coating with either zinc, lead or aluminium caused the welds to be porous, and the zinc and lead gave off poisonous fumes during the welding.

PROPERTIES AND TESTS

(Continued from pp. 32 A-38 A)

Internal Stresses in Cast Iron Rolls in Relation to Service Conditions. N. Krupnik. (Iron and Steel, 1941, vol. 15, Nov., pp. 29–32). An English translation is presented of an article which appeared in Stal, 1939, No. 10–11, pp. 53–57. (See Journ. I. and

S.I., 1941, No. I., p. 62 A).

Comparison of the Mechanical Properties of Steels Made from Scrap Iron and from Spongy Iron. T. Atuta. (Tetsu to Hagane, 1941, vol. 27, July, pp. 471–486). (In Japanese). The author reports on tests made with the object of verifying reports that the mechanical properties of steel made from sponge iron excelled those of steel made from scrap iron. Six steels with carbon in the 0·2-1·3% range were selected and tested and, contrary to expectation, the steel made with scrap iron was found to be tougher and harder.

High-Speed Tension Tests at Elevated Temperatures—Parts II. and III. A. Nádai and M. J. Manjoine. (Journal of Applied Mechanics, 1941, vol. 8, June, pp. A-77-A-91). A high-speed tensile testing machine was described and some results obtained with it at high temperatures using copper specimens were given in Part I. (See Journ. I. and S.I., 1940, No. II., p. 160 A). In Part II. a description is given of a constant-strain-rate testing machine which operates at slow speeds, and the results of tests with both machines on iron, steel and aluminium specimens are reported. The fastest rate of stretching was one billion times that of the slowest rate.

At the highest velocity, corresponding to a tension test lasting only 0.001 sec., and at temperatures close to the melting point, a remark. ably large resistance to deformation was noted. For some ferrous metals, including a very pure iron, the resistance to deformation showed a well-defined maximum and minimum of stress as a function of the temperature for a given rate of strain. For the ferrous metals the temperature range of maximum strength depends on the rate of stretching; at slow rates the middle point of this range is about 200° C. (corresponding to the "blue-brittleness" range), whilst at very fast rates of strain the maximum strength is observed at about 550° C. Curves showing the relation of the resistance to deformation and the strain rates and the temperature are given for several metals. In a high-speed tensile test on pure iron, an instantaneous rise in temperature of about 50°C, was observed: this was caused by the conversion of the work of deformation into heat. In a mathematical treatise in Part III, it is shown that it is possible, at least in the higher range of temperatures, to predict the shapes of the stress-strain curves in tension tests and the characteristic contours of the necked portions of test-pieces.

Technical Cohesive Strength (Static Crack Strength). W. Kuntze. (Iron and Steel Institute, 1941, Translation No. 26). An English translation of a pamphlet published by Julius Springer, Berlin, in 1932.

Effect of Grain Size and Heat Treatment upon Impact-Toughness at Low Temperatures of Medium Carbon Forging Steel. S. J. Rosenberg and D. H. Gagon. (Journal of Research of the National Bureau of Standards, 1941, vol. 27, Aug., pp. 159-168). The authors report on an investigation of the influence of the grain size and heat treatment on the impact strength of 0.50% carbon steel at temperatures from 100° C. down to -78° C. The steels tested, either as hot-rolled or as normalised, had low impact strengths. In the hot-rolled condition the steel was brittle at room temperature, and the temperature below which it became brittle on cooling was above 100° C. Normalising the hot-rolled steel improved the impact strength at room temperature and above. Differences in the grain size of the normalised steel appeared to affect the impact strength, for the smaller the grain size, the lower was the temperature at which cold-brittleness was manifested. The impact strength was markedly improved by hardening and tempering, but normalising prior to heat treatment had no effect on this property. The impact strength at room temperature was no criterion for the impact strength at lower temperatures. Specimens from different heats of steel appeared to have an inherent resistance to impact, the degree of which depends on factors which are not yet fully understood.

Stainless Steel. J. M. Bandel. (Iron Age, 1941, vol. 148, Oct. 9, pp. 45–52, 162). The author reports on an investigation of the effect of various degrees of cold deformation on the mechanical properties of 18/8, 17/7 and 18/5 chromium-nickel steels and of 18/5/5 and 18/2/8 chromium-nickel-manganese steels. In all cases

hot-rolled strip was annealed, pickled and cold-rolled to a finished thickness of $0.\overline{035}$ in. Some specimens were given a low-temperature stress-relieving treatment. The transverse tensile strength of 18/8 strip was somewhat greater than the comparable longitudinal values. The tensile strength of the 17/7 quality did not exhibit marked directional effects or response to the low-temperature treatment. The greatest compressive strengths of these two steels were obtained in the transverse direction, and these were considerably improved by the heat treatment. For any given value of elongation the corresponding values of tensile strength, yield strength and compressive yield strength were greater for the 17/7 alloy than for the 18/8 alloy. Strip having an elongation of 10-15% on 2 in. was sufficiently ductile for the fabrication required in most structural members. In the case of the 18/5/5 and 18/2/8 steels it was observed that the tensile strength increased and the elongation decreased when the degree of cold-reduction was increased from 25% to 35%. Test data are presented in a comprehensive table and by graphs.

The Measurement of Residual Stresses in Metal. G. Sachs and G. Espey. (Iron Age, 1941, vol. 148, Sept. 18, pp. 63–71; Sept. 25, pp. 36–40). The authors review the literature on methods of determining the magnitude and distribution of residual stresses in metal products of various shapes giving several examples of the calculations involved and describing the technique for measuring minute amounts of strain. There are 92 references to the literature.

The Occurrence of Folding Cracks when Rolling Steel with Unrestricted Lateral Spread. A. Pomp and W. Lueg. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 16, pp. 241-249). The authors investigated the rolling conditions which promoted the formation of folding cracks when rolling flat steel bars. These cracks occur when steel which has rough edges after rolling with unrestricted lateral spread is given additional horizontal and edging passes. Four types of steel were investigated; these contained: (a) Carbon 0.88%; (b) carbon 0.37%, chromium 1.05% and molybdenum 0.17%; (c) carbon 0.13% and nickel 3.74%; and (d) carbon 0.41%, chromium 13.6% and nickel 0.20%. The rolling temperatures were varied in the range $700-1200^\circ$ C. and the surfaces were examined with the naked eve, by hot-etching and by the magnetic-powder process. It was observed that the surface roughness of all four steels increased with the temperature of rolling. Steel (a) had the smoothest surface; next came steel (b) and then steel (c). The knife-blade steel (d) had a smooth surface, but after rolling at 1000-1100° C. it had many surface cracks in the direction of rolling. Deep-etching revealed many pickling cracks in steel (d), the cause of which was found to be the shear stresses set up by the flow of the material towards the edges. Of the four steels, steel (c) had the greatest tendency to form folding cracks, but with steel (d) there was a certain temperature range in which the flow of metal across the section was

likely to be very uneven. The cracks in the knife-blade steel revealed by hot-etching could be prevented by cooling the strip in the furnace after rolling, or by coating it with a saturated borax solution

before rolling.

Fatigue Test Results. I. and II. E. C. Hartmann. (Machinist, 1941, vol. 85, Oct. 4, pp. 226E–227E; Nov. 1, pp. 250E–251E). The author quotes an example of how fatigue-test results can be misused by applying them to cases in design where the test conditions do not represent the service conditions. He then considers how the following factors affect fatigue test results: (1) Stress range; (2) number of cycles; (3) condition of the surface of the metal; (4) influence of holes, notches and other stress raisers; and (5) effect of plastic movement at stresses above the elastic range.

Method of Stressing and the Fatigue Strength of Cast Iron and Malleable Cast Iron. A. Pomp and M. Hempel. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Mar., pp. 439–449). An abridged account of the investigation reported in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 11, pp. 169–201 is presented. (See Journ. I. and S.I., 1941, No. II.

p. 216 A).

Durability of Gears. (Automobile Engineer, 1941, vol. 31, Oct., pp. 328–336). A report is presented of the results of tests on seven automobile gear steels carried out over a period of three years by the Research Department of the Institution of Automobile Engineers. The phenomena connected with surface failure and the effects ascribed to different methods of finishing the gears were examined.

The Wear of Cylinder Liners. J. E. Hurst. (Iron and Steel, 1941, vol. 15, Oct., pp. 8–11; Nov., pp. 37–39). The author discusses the wear of cylinder liners for internal-combustion engines. He presents several diagrams showing the position of the zones of maximum wear and discusses the thermal and mechanical stresses

acting on cylinder walls and their relation to these zones.

Metallurgy and Magnetism. H. J. Merchant. (Journal of the Birmingham Metallurgical Society, 1941, vol. 21, Sept., pp. 210–240). In this general discussion of the magnetic properties of ferrous alloys and the methods by which the metallurgist controls these properties, the author first explains in simple language the terms permeability, induction, hysteresis, coercive force and eddy currents. He then states the requirements of magnetic materials and shows to what extent these are met by the iron-silicon alloys containing up to 5% of silicon. The applications of ten grades of this alloy with 0.2-4.2% of silicon and 0.08-0.03% of carbon are given, after which the properties of nickel-iron alloys and of the permanent magnet alloys are dealt with. In conclusion a number of instances of the manner in which the sciences of magnetism and metallurgy serve each other are given.

An Extensometer for the Measurement of Magnetostriction in Sheet Materials. F. Brailsford. (Journal of Scientific Instruments, 1942—i

1941, vol. 18, Nov., pp. 221–223). An extensometer for measuring magnetostriction in steel sheets is described, a feature of the design being its compactness. With an illuminated scale at a distance of 15 ft., a magnification of approximately 100,000 is obtained and a

method of checking the calibration is given.

Detection of Defects by Electrical Conductivity and Resistance. W. Bayliss. (Welding Industry, 1941, vol. 9, Nov., pp. 237, 241). The author discusses the possibility of adapting the Sperry system of detecting faults in rails to the testing of chains. He refers to preliminary experiments which have proved successful for finding the weakest links in chains. Chains made from wrought iron are not such good subjects for conductivity tests as those made from wrought steel, and those made from cast steel are liable to great variations in heterogeneity. In using sharp fluctuations in voltage curves as evidence of faults, different standards of voltage drop will have to be established for wrought iron, wrought steel and cast steel chain.

Heat Resisting Steels. (Automobile Engineer, 1941, vol. 31, Nov. 6, pp. 371–373). The characteristics of heat-resisting alloy steels containing silicon, nickel and chromium are discussed with particular reference to the effect of scaling and creep on their mechanical properties at temperatures exceeding 300° C. Reference is made to the "time-yield" short-time creep test at elevated temperatures which has been developed by the Brown-Firth Research Laboratories. At any given temperature the time-yield value is the greatest stress that, during the first 24 hr. of the test, causes an extension less than 0.5% of the gauge length and, during the next 48 hr., causes a rate of creep that does not exceed 10-6 in.

per inch per hour.

Creep Tests with Stepped Increasing Loads at 700° and 800°. A. Krisch and S. Eckardt. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Mar., pp. 451–453). The authors describe an investigation, by means of 1-hour and 10-hour stepped tests at 700° and 800° C., of the creep properties of four of the austenitic chromium-manganese steels and two of the chromium-cobalt steels which were subjected to long-time tests by Pomp and Krisch (see Journ. I. and S.I., 1941, No. II., p. 222 A). The one-hour stepped test was described recently by Esser and Eckardt (see Journ. I. and S.I., 1941, No. II., p. 222 A). A comparison of the results obtained by the short-time and the long-time tests showed that the values obtained by the former were too high, so that long-time tests are necessary for the correct evaluation of the creep properties of these steels at high temperatures.

Effect of the Hydrogen Content, Hydrogen Permeability and Hydrogen Solubility on Flake Formation in Steel. H. Bennek and G. Klotzbach. (Stahl und Eisen, 1941, vol. 61, June 19, pp. 597–606; June 26, pp. 624–630). In the first part of their paper on the effect of the hydrogen content, solubility and permeability on hairline crack formation the authors describe in detail the methods they

applied for the evaluation of these three factors. With regard to the determination of the hydrogen content, they consider melting of the specimen with tin more advantageous than any of the other procedures known, the limit of error being ±0.25 c.c. of hydrogen per 100 g. of sample for a sample weight of 20 g. For the determination of the permeability of steel to hydrogen the authors developed a complicated apparatus—a sketch of which is shown which, with certain modifications, served also for the evaluation of the solubility of hydrogen in steel specimens. They give data obtained with this apparatus for the hydrogen solubility and permeability up to 1100° C. of various carbon steels (0·3-1% of carbon) and alloy steels, especially those containing: (a) Carbon 1%, chromium and steers, especially those containing. (a) carbon 1.5%; (b) carbon 0.2-0.3%, chromium 0.7%, nickel 3.5%; (c) carbon 0.1-0.2%, chromium 1.5%, nickel 4%, tungsten 1%; and (d) chromium 18%, nickel 8%. They found that the rate of hydrogen evolution at room temperature is greatly dependent on the structure of the material, while the alloy composition as such is of secondary importance in low-alloy steels. Also at higher temperatures, up to 1500° C., the permeability is affected by the structure. With the exception of the austenitic chromium-nickel steel, all the steels examined showed about the same solubility for hydrogen at high temperatures. After quenching to room temperature, however, the hydrogen contents of specimens saturated at high temperatures became very different, a finding which the authors assume to be due to differences in the course of the permeability

In the second part of the paper the relations between the hydrogen content and the liability to flake formation are dealt with, and the minimum amounts of hydrogen are stated which, under certain working conditions, lead to flake formation. In conclusion the authors discuss the reasons for the effect of the hydrogen content, permeability and solubility on hair-line crack formation, explaining why certain modes of heat treatment lead to their formation and recommending others by which their formation can be suppressed.

The Combined Effect of Hydrogen and Stresses on the Formation of Hair-Line Cracks. E. Houdremont and H. Schrader. (Stahl und Eisen, 1941, vol. 61, July 3, pp. 649–653). The authors studied the combined effect of hydrogen and of quenching, working and transformation stresses on the liability to the formation of hair-line cracks. The results indicated that hair-line cracks are only formed in the presence of hydrogen, but that stresses have an additional effect. They annealed specimens of plain carbon steel and of chromium, chromium-nickel and non-transforming 4% silicon steel in hydrogen atmosphere containing water vapour, and studied the effect of the temperature and duration of annealing and of the rate of cooling on the development of hair-line cracks. They found that with increasing rates of cooling smaller amounts of hydrogen were sufficient for their formation. Further, they studied the effect of the

transformation of the structure during cooling and, by producing hair-line cracks also in the non-transforming steel under examination, they proved that the stresses coinciding with the formation of martensite are not indispensable for the development of hair-line cracks. They do, however, facilitate their development. The authors assume this to be due, first, to the fact that the increased liberation of hydrogen at the γ - α transformation takes place at lower temperatures at which the permeability to hydrogen has become smaller, and, secondly, to the state of stress caused by the hardening process. Similarly, the authors also found that mechanical stresses, especially tensile stresses, enhanced the formation of hair-line cracks and that they could even affect their orientation.

Hydrogen as an Alloying Element for Steel and Cast Iron. E. Houdremont and P. A. Heller. (Stahl und Eisen, 1941, vol. 61, Aug. 7, pp. 756-759). The authors report on an investigation of the manner in which impregnation with hydrogen affects the structure of cast iron and steel. The amount of hydrogen necessary to act as a carbide stabiliser in cast iron is about 0.5-0.7 c.c. per 100 g. The mechanism of the action of hydrogen is not clear. Specimens impregnated with hydrogen exhibit a well-developed lamellar pearlitic structure and graphite. The hydrogen acts to a certain extent to develop the structure in the direction of a metastable ironcementite system. The effect is similar to that of hydrogen in steel. In steel the hydrogen increases the hardenability. Impregnating hydrogen into steels which have a tendency to form abnormal structures (such as cementite agglomerates), causes the formation of normal cementite and pearlife structures. The results of tests discussed by the authors are in agreement with the above, and their general conclusion is that hydrogen acts as an alloving element in the same sense as manganese or chromium, but excluding the additional effects these elements have on cast iron.

Study of the Silicon Contained in Steel. I. Effect of Silicon on the Quality of Low-Nickel Steels. K. Ôta. (Tetsu to Hagane, 1941, vol. 27, July, pp. 441–454). (In Japanese). The author studied the effect of increasing the silicon content on the quality of structural low-nickel steels made in an acid open-hearth furnace. A marked change in the properties was noted when the silicon was increased above 0.23%, for above this value the steel had a more refined grain, better hardenability, and, when larger sections were heat-treated, the mechanical properties of the core were greatly improved.

Alloy Cast-Irons. (Automobile Engineer, 1941, vol. 31, Nov. 6, pp. 383–385, 388). Particulars are given of three alloy cast irons developed by the Midland Motor Cylinder Co., Ltd., for making automobile cylinder blocks, camshafts and crankshafts. These have the registered trade names "Chromidium" (total carbon 3·10–3·35%, combined carbon 0·55–0·75%, chromium 0·20–0·40%), "Monikrom" (total carbon 3·10–3·40%, nickel 0·15–0·25%,

chromium 0.80-1.00%, molybdenum 0.15-0.25%) and "Cromol"

(composition not stated).

Molybdenum High-Speed Steels. J. P. Gill and R. S. Rose. (Metal Progress, 1941, vol. 40, Sept., pp. 283–288; Iron Age, 1941, vol. 148, Sept. 25, pp. 33–35). The authors discuss the development and properties of the molybdenum-chromium high-speed steels and compare these with the properties of high-tungsten steels. They present tables in which the thermal conductivity and hardness of these steels at different temperatures are compared.

Lead-Bearing Steels. (Automobile Engineer, 1941, vol. 31, Nov. 6, pp. 386–388). A survey is presented of the properties of

"Ledloy" lead-bearing steel.

The Effect of Misch Metal on Cast Iron. W. Baukloh and H. Meierling. (Giesserei, 1940, vol. 27, Sept. 6, pp. 337–341). The authors report on an investigation of the effect of additions of up to 2% of cerium on the properties of cast iron. It was established that the tensile and bending properties of iron were improved and that desulphurisation was promoted by the presence of this metal. The flowing power of the iron was improved by small additions of misch metal, whilst increased quantities caused the rapid formation of an oxide of cerium which reduced the flowing power.

Metallurgical Progress and the Steam Engineer. L. Sanderson. (Steam Engineer, 1941, vol. 11, Nov., pp. 31–33). The author reviews the properties of a number of special steels and iron alloys of interest to the steam engineer, which have been developed in recent years. These include alloy steels for seamless boiler and superheater tubes; a weldable abrasion-resisting steel containing 11·0–13·5% of manganese, 0·6–0·95% of silicon and 2·5–3·5% of nickel, known as "Manganal"; and a nickel cast iron for pump castings.

Basic-Bessemer Steel Killed with Silicon and Aluminium for Ship's Rivets. H. Hauttmann. (Stahl und Eisen, 1941, vol. 61, Aug. 28, pp. 801–806). The author reports on an investigation of the properties of rivets made of (a) silicon-killed open-hearth steel to German Lloyd's requirements for ship's rivets; (b) basic-Bessemer steel killed with silicon and aluminium as proposed by Gutehoffnungshütte Oberhausen, A.-G.; (c) open-hearth rimming steel St 34·13; and (d) basic-Bessemer rimming steel St 34·13. The mechanical and ageing properties as well as the hot- and cold-deformation properties are compared and the results obtained are given in tables and diagrams. The data show that both in the as-rolled and annealed state rivets of steel (b) are not inferior to rivets of steel (a), and that they are better than rivets of steels (c) and (d).

Fabrication Considerations when Selecting a Steel. G. T. Williams. (Metal Progress, 1941, vol. 40, Sept., pp. 289–292, 378. 382). The author considers some factors affecting the forgeability, deep-drawing properties, weldability and machinability of carbon

and low-alloy steels.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 38 A-39 A)

Experience in the Application of the Magnetic Powder Process of Testing for Cracks. H. Schrader. (Iron and Steel Institute, 1941, Translation Series, No. 40). An English translation of a paper which appeared in Stahl und Eisen, 1940, vol. 60, July 18, pp. 634-640; July 25, pp. 655-658. (See Journ. I. and S.I., 1941,

No. II., p. 99 A).

Magnetic Testing. J. Seifert. (Iron Age, 1941, vol. 148, Oct. 9, pp. 64–73). The author reports on an investigation of the characteristics of five different commercially available magnetic powders for the detection of cracks in steel by the magnetic-powder method. The distinctness with which a powder could be detected on the material being tested, its adherence and its response to the depth of the crack from the surface were determined. The results are tabulated and illustrated.

The Electron Microscope, the Supermicroscope and Metallurgical Research. W. Henneberg. (Stahl und Eisen, 1941, vol. 61, Aug. 14, pp. 769–776). The author explains the principles and methods of working of the electron microscope and describes some existing emission and electrostatic focusing electron microscopes and their application for the study of smokes, rust, and oxide films on iron and aluminium.

Electron Microscopy. B. von Borries. (Stahl und Eisen, 1941, vol. 61, July 31, pp. 725–735). The author presents a review of the principles, development and present knowledge of the electron microscope and describes some of the well-known instruments such as the Siemens and those of the Radio Corporation of America.

Preparing Metallurgical Specimens. B. Walsh. (Iron Age, 1941, vol. 148, Sept. 18, pp. 53–57). The author describes the equipment and sequence of operations for the rapid polishing of metallurgical specimens. After rough-polishing on a horizontal belt machine, a revolving disc of stainless steel is used on to which emery cloths of different degrees of fineness and final-polishing cloths can be clamped by a ring. This disc is driven by a ¼-h.p. motor with a control to vary the speed between 700 and 1150 r.p.m.

Bibliography on Grain Size in Steel (Including Abnormality, Normality and Hardenability) with an Appendix Bibliography on the Effect of Grain Size on the Magnetic Properties of Steel. (Covering the Period 1922 to 1940). (Iron and Steel Institute, 1941, Biblio-

graphical Series, No. 9).

The Austenitic Grain Size of Steel. R. Kawai. (Tetsu to Hagane, 1941, vol. 27, July, pp. 462–470). (In Japanese). The author discusses methods of determining the size of austenite grains in steel and describes a method which he has himself developed.

Transformation Structures of Some Forty Carbon Steels. (Metals and Alloys, 1941, vol. 14, Sept., pp. 318–319). Some information on the heat treatment and structure of a variety of 0·40% carbon steels compiled from test results obtained in the research laboratory of the Climax Molybdenum Co. is presented. A large number of micrographs at 1000 diameters of plain carbon steel and of 0·40% carbon steel alloyed with chromium, nickel and molybdenum, transformed at various temperatures in the 500–1250° F. range, are reproduced and explanations are given of the use of these, in conjunction with Davenport's S-curves, for the determination of the necessary heat treatment to produce a desired structure and hardness.

The Decomposition of Austenite in Carbon Steels. H. Lange. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 15, pp. 229-240). The author reports on an isothermal investigation of the decomposition of austenite in four steels containing carbon 1·16%, 0·97%, 0·55% and 0·41%, respectively. This work may be regarded as an extension of that of Wever and Hänsel (see Journ. I. and S.I., 1937, No. II., p. 95 A). The magnetic balance referred to in the earlier paper was again used. The results indicated that in these steels the formation of ferrite and pearlite proceed independently and that the processes overlap. The relation between the rate of formation of these components and both the initial and the formation temperatures was determined. The results observed with a steel of almost eutectoid composition were in good agreement with those obtained with a hyper-eutectoid steel which were reported in the paper referred to above. A series of micrographs is also presented which shows the relation between the velocity of pearlite formation and the initial temperature. When the amounts of pearlite formed were plotted in relation to time using the half-conversion value as a unit of time, similar pearlite formation curves were produced for all the steels investigated for all decomposition temperatures. The curve was an S-curve symmetrical about its middle point, and the branches may be approximately represented by parabolas of the third order. The ferrite formation curves, on the other hand, showed the highest transformation velocity at the commencement of transformation, after which it proceeded as a monomolecular The course of the cementite formation in relation to time could not be determined. The maximum velocity of pearlite formation diminishes with increasing carbon content up to the eutectoid composition, after which it presumably rises again. Increasing the carbon content also lowers the temperature of the maximum transformation velocity.

The Freezing Point of Iron. (Metallurgist, 1941, vol. 13, Oct., pp. 34–35). Some results of attempts to determine the freezing point of pure iron are quoted from the literature. The determinations vary in the range 1527–1539° C. Experiments have also been

made to establish the effects of various impurities and alloying elements on the melting point of steel, and the results indicated that, in general, when a number of other elements are present in iron, the effect of any one is the same as it would be if the other elements were not present, and the total effect of all the elements is equal to the sum of the effects of the elements taken separately. A table is presented showing separately the amounts by which the freezing point is depressed by the presence of certain percentages of seventeen different elements.

The Iron/Iron-Sulphide/Iron-Silicide System. R. Vogel, C. Uschinski and U. Theune. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Mar., pp. 455–462). The authors report on an investigation of the iron/iron-sulphide/iron-silicide system by thermal and microscopical examinations of melts prepared by first adding silicon to the molten iron, allowing time for the temperature increase due to the formation of iron silicide to subside, and then adding the sulphur. It was observed that in the liquid state iron sulphide and iron silicide were only slightly soluble in each other. This is the cause of the extensive miscibility gap in the region investigated. Its course and that of the tie-lines and the occurrence of a lower critical point near to the iron/iron-sulphide boundary have been established. Special details are a three-phase equilibrium, a maximum temperature on the miscibility surface and a eutectic three-phase equilibrium with a temperature maximum, one solid phase of which is the superstructure solid solution Fe, Si. Silicon is one of those elements, such as carbon and phosphorus, which, when added to molten iron containing sulphur, causes a liquid sulphur-rich layer to separate out; it thus favours the effect of manganese in desulphurising pig-iron.

CORROSION OF IRON AND STEEL

(Continued from pp. 39 A-40 A)

Factors Affecting Atmospheric Corrosion Tests on Unalloyed and Low-Alloy Steels. K.-F. Mewes and K. Daeves. (Stahl und Eisen, 1941, vol. 61, Sept. 4, pp. 826–834). The authors investigated how such factors as shape of specimen, position, surface condition and climate affect the results of atmospheric corrosion tests. From an evaluation of numerous test results they make the following recommendations: (1) To determine the general relative behaviour of different steels, the largest possible number of specimens should be exposed under different climatic conditions and, in industrial atmospheres, they should be placed at different angles. For testing wire, some samples should be placed near the ground and others at the top of a fence-post. (2) Comparative atmospheric corrosion tests should be carried out with the specimens having a

known rate of corrosion adjacent to those being tested. (3) The duration of the test should be as long as possible, with inspection and weighing at intervals in order that the progress of corrosion can be observed and any abnormal results detected. In atmospheres which cause the rate of corrosion to diminish gradually it is essential to weigh at short intervals. (4) It is preferable to employ chemical means to remove the rust before weighing, and, as a check, it is advisable to weigh the specimen in the rusty state and after mechanical cleaning. (5) As a specimen which has once had the rust removed from it cannot be used for further atmospheric tests, a sufficient number of specimens must be exposed at the commencement of the test to ensure that one untouched specimen remains at the end of the whole test period; this can be easily done with wire specimens by cutting off pieces from each end at each inspection as the test proceeds, an untouched centre portion

being left for final examination.

Intergranular Corrosion in Austenitic Stainless Steels. III. and IV. J. H. G. Monypenny. (Metallurgia, 1941, vol. 24, Sept., pp. 137-142; Oct., pp. 170-174, 194). Continuation of a series of articles (see Journ. I. and S.I., 1941, No. II., p. 232 A). Having described in Parts I. and II. the underlying causes of intergranular corrosion in austenitic stainless steels, the author considers in Part III. methods of preventing its occurrence. The following methods are discussed: (1) Reduction of carbon content so that no carbide is precipitated during heating at any temperature; (2) control of carbide precipitation so that continuous films of chromiumdepleted material are not produced—this may be achieved in the plain chromium-nickel steels, or it may be aided by the presence of other alloys; and (3) additions of suitable alloys which will either cause the precipitation of carbides other than that of chromium, or will increase the solubility of carbon in the austenitic matrix. In Part IV. the susceptibility of vanadium steels and of chromium-nickel steels to intergranular corrosion in relation to the percentage of ferrite in the structure is discussed. In considering the practical application of numerous test results, the author points out that two vital questions must be borne in mind when deciding whether a given steel processed in a given manner will be satisfactory for some particular purpose; these are the corrosive conditions to which the finished article will be subjected, and the maximum time the steel, after final heat treatment, will be heated in the sensitising range of temperature, both during fabrication and in service. Some examples from different industries which show the importance of these factors are given.

ANALYSIS

Detection of Certain Metals in Minerals and Ores. H. B. Van Valkenburgh and T. C. Crawford. (Industrial and Engineering Chemistry, Analytical Edition, 1941, vol. 13, July 15, pp. 459–460). When fused with ammonium hypophosphite many minerals and ores are decomposed, forming a highly coloured melt. The colour of the melt, in certain cases after treatment with water or hydrogen peroxide, was chosen by the authors as the basis of tests for chromium, cobalt, columbium, manganese, molybdenum, tellurium, titanium, uranium, vanadium and tungsten. The detection of these metals by the authors' method is only possible in certain minerals, however, a list of which is given.

Organic Reagents for the Quantitative Analysis of Iron and Steel. E. C. Pigott. (Metallurgia, 1941, vol. 24, Sept., pp. 157–159). The author presents a survey of the literature on the application of the newer organic reagents in making gravimetric and colorimetric analyses of iron and steel. There are 113 references to the

literature.

Factors Affecting the Accuracy of Gravimetric Combustion Carbon Determinations. E. T. Saxer, R. E. Minto and R. A. Clark. (Blast Furnace and Steel Plant, 1941, vol. 29, July, pp. 718-722). The authors have found that the accuracy of the determinations of carbon in steel is greatly affected by the accuracy with which the weight of the absorption tube is obtained. In the present paper some factors affecting this weight are examined. Dust can be eliminated by brushing with a camel-hair brush before each weighing. Carbon-dioxide absorption tubes should not be left unstoppered after use, otherwise rapid changes in weight will occur. After displacing the air in a new ascarite tube with oxygen, the first weight is always low, but the correct weight is found after a second determination. There is a rise in the temperature of the carbon-dioxide absorption tube after ignition with increasing percentages of carbon in the sample. Iron-oxide dust is carried over from the furnace to the reagents, and it is a good plan to have a cotton filter after the last reagent and before the absorption tube.

Oxidation of Graphite in the Analysis of Ferrous Metals. R. H. Steinberg and F. W. Smith. (Industrial and Engineering Chemistry, Analytical Edition, 1941, vol. 13, June 15, pp. 392–393). In order to avoid the elaborate filtering-off of graphite from the solution of the sample before determining the manganese and carbon contents of irons containing graphitic carbon, the authors suggest oxidising the graphite. This is achieved by dissolving the sample in fuming perchloric acid in the presence of sodium dichromate (0·2 g. per g. of alloy). The chromium is subsequently volatilised by the addition of sodium chloride. The procedures for the determination

of manganese and phosphorus respectively are described in detail. A loss of the latter element due to the formation of hydrides is prevented by the addition of dilute nitric acid. The procedures suggested effect a time saving of 40–50 min., and the results obtained are in good agreement with those of the A.S.T.M. standard method.

Investigations of the Effect of the Vaporisation of Iron on the Determination of Oxygen in Ferro-Tungsten by the Hot-Extraction Method. G. Thanheiser and R. Paulus. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 14, pp. 217-228). In making chemical analysis of ferro-tungsten it has been observed when melting it in a graphite crucible that iron vapour is often formed, whilst this does not happen when the alloy is high in carbon. This vaporisation causes the oxygen determination to be too low. The amount of iron that vaporises depends on the composition of the ferro-tungsten. If this is high in tungsten and low in carbon, strong vaporisation occurs. The authors report on their investigation of this phenomenon. X-ray powder diagrams of samples of ferro-tungsten of different composition before and after vaporisation showed that the pure iron which vaporised originated from an iron-tungsten double carbide with the probably composition $\mathrm{Fe_3W_3C}$ which, by taking up carbon, was converted into $\mathrm{W_2C}$ and pure iron. At the prevailing temperature and pressure this iron had a sufficiently high vapour-pressure to permit most of it to be vaporised before it could be stabilised by the slow diffusion of carbon from the crucible wall.

Determining Metallic Iron in Iron Oxides and Slags. J. P. Riott. (Industrial and Engineering Chemistry, Analytical Edition, 1941, vol. 13, Aug., pp. 546–549). The author discusses the disadvantages of the mercuric chloride and copper sulphate methods of determining the metallic iron in slags, ores and mixed oxides of iron and describes a new method using cupric potassium chloride. Experiments have shown that the new method gives values comparable with those obtained with mercuric chloride in the presence of magnetite, mixed oxides and sponge iron, whereas copper sulphate under these conditions gives high results. The method is limited to the determination of up to 0·1 g. of metallic iron in the sample.

Short Volumetric Method for the Determination of Iron in Silicates. C. M. Nicholson. (Bulletin of the American Ceramic Society, 1941, vol. 20, Oct., pp. 331–334). The author describes a rapid and accurate method for determining iron as ferric oxide in silicates. The procedure involves: (1) fusing the sample with a mixture of sodium carbonate and borax, (2) dissolving the melt completely in sulphuric acid, (3) reducing the solution in a Jones reductor, and (4) titrating with ceric sulphate solution using

orthophenanthroline as an indicator.

Analysis of Lead in Steel. R. B. Rumsey and H. B. Gordon. (Chemist Analyst, 1940, vol. 29, Aug., pp. 62-63). The authors

give details of an analytical procedure for detecting and determining lead in steel.

Simplified Molybdenum Determination. G. M. Poole. (Iron Age, 1941, vol. 148, Oct. 9, pp. 62, 164, 165). The author describes modifications of James' method for the colorimetric determination of molybdenum in steel (see Journ. I. and S.I., 1932, No. I., p. 689). The modifications are for the purpose of making the original procedure more suitable for higher molybdenum contents, i.e., up to

6%.

Methods for the Photometric Determination of Niobium and Tantalum in Steel, Ferro-Alloys and Slags. G. Thanheiser. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 17, pp. 255-265). The author describes photometric methods for determining columbium and tantalum when present together, with and without the presence of titanium. in steel, ferro-alloys and slags. The basis for the columbium determination is its yellow colour with hydrogen peroxide in a concentrated mixture of sulphuric and phosphoric acids. By mixing these acids in the right proportions the colour interference of titanium is suppressed to such a degree that the columbium determination is practically unaffected by any titanium which may be present; only if more than 1% of this element is present is it necessary to make a small correction. In this acid mixture the extinction of columbium is reduced to two-thirds of the value it would have in concentrated sulphuric acid, but it still remains at a sufficiently high value for accurate determinations to be made. The basis of tantalum determinations is the yellow colour this element produces with pyrogallol in a 3% ammonium oxalate solution. As titanium with pyrogallol also produces a yellow colour, a simultaneous determination of this element independent of the columbium and tantalum is necessary so that the proper correction can be made. The titanium determination is made with chromotropic acid in the same solution. The known methods of separating columbium and tanalum oxides from solutions of steel, ferro-alloys and slags are reviewed. The results of check analyses show that the photometric methods described give accurate determinations.

Determination of Tin in Cast Iron and Plain Steel. E. T. Saxer and R. E. Minto. (Steel, 1941, vol. 108, July 21, pp. 66, 91). The authors describe an improved method for determining the amount of tin in cast iron and ordinary carbon steel. It is claimed that the time required for the actual reduction of the stannic chloride to stannous chloride is greatly reduced, that the method is accurate and that there is a sharp end-point to the titration with potassium iodate solution. The procedure, which is described in detail, requires 10 g. of a prepared iron-antimony alloy known as "Stan-

reduce"; of this amount 9.4 g, can be recovered.

Direct Determination of Vanadium in the Presence of Titanium and Iron. S. S. Cole and C. A. Kumins. (Bulletin of the American

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Ceramic Society, 1941, vol. 20, Oct., pp. 329–331). The authors describe a rapid and accurate method of determining vanadium in the presence of iron and titanium using orthophenanthroline as an indicator to establish the vanadium in tetravalent form. The solution is subsequently boiled to destroy the indicator and titrated with KMnO₄; the results obtained are accurate within $\pm 1\%$. Improvements in technique for determining titanium in the presence of vanadium and iron are discussed.

Determination of Zirconium in Steel. W. G. Hayes and E. W. Jones. (Industrial and Engineering Chemistry, Analytical Edition, 1941, vol. 13, Sept., pp. 603–604). The authors describe a routine method for determining zirconium in steel based on the precipitation of zirconium by p-dimethylaminoazophenylarsonic acid together with the colorimetric measurement of the precipitated reagent. The analysis takes 2 hr., and the results do not deviate by more than 0.005% from those obtained by the selenious acid method.

A Spectrographic Analysis of Iron for Tellurium. R. E. Nusbaum and J. W. Hackett. (Journal of the Optical Society of America, 1941, vol. 31, Oct., pp. 620–626). It has been found that the presence of several thousandths of 1% of tellurium in malleable cast iron has the effect of keeping the carbon in the combined state during the pouring and solidification process, but it has little effect upon the subsequent annealing process. The use of tellurium to shorten the annealing time necessitates analyses covering the range of concentrations from 0.001% to 0.01%. In the present paper the authors describe the spectrographic apparatus and technique for determining such small quantities of tellurium in iron. At present the time required to prepare a sample and complete its analysis is about 30 min., but methods for reducing this to about 15 min, are suggested.

Use of the Spectroscope in Determining Residual Alloys in Drawing Steels. L. Selmi. (American Iron and Steel Institute: Heat Treating and Forging, 1941, vol. 27, June, pp. 291, 304). The author describes how a works producing deep-drawing-quality steel applied the spectroscope to make rapid determinations of the residual amounts of copper, chromium, molybdenum, tin, nickel and aluminium in the steel with a view to ascertaining whether any of these elements had a detrimental effect on the properties of the steel. It was established that tin did have a detrimental influence on the deep-drawing properties if more than about 0.02% is present. No definite conclusions regarding the effect of the other elements

were arrived at.

The Lundegardh Flame Method of Spectrographic Analysis. V. R. Ellis. (Journal of the Optical Society of America, 1941, vol. 31, Aug., pp. 534–542). The author gives a fairly detailed description of the Lundegardh flame method of spectrographic analysis. The method is highly sensitive in the detection of minute

quantities of alkalis and the alkaline-earth metals, but an extension of its application for determining other metals is advocated. For this method the material to be analysed is placed in solution, and the solution is converted into a fine spray by means of an atomiser and compressed air; the spray and air are mixed with acetylene and the mixture is burnt in front of, and 4–5 cm. away from, the slit of the spectrograph. Some advantages of this method over the arc and spark methods are discussed.

The Application of the Characteristic Curve of the Photographic Plate in the Quantitative Spectral Analysis. T. Matubara and Y. Yosida. (Nippon Kinzoku Gakkai-Si, 1941, vol. 5, Apr., pp. 157–163). (In Japanese). The authors discuss the difficulties met with in making quantitative spectrum analyses of alloys by both the relative and absolute methods, and describe a simplified

method which they developed.

A Rapid Method for the Ultimate Analysis of Coal. R. Belcher and C. E. Spooner. (Fuel in Science and Practice, 1941, vol. 20, Aug.—Sept., pp. 130–133). The authors describe a method for the simultaneous determination of carbon, hydrogen, sulphur and chlorine by the combustion of 0.5 g. of coal in a fast stream of oxygen at a temperature of 1350° C. The combustion takes only 10 min. The sulphur (as oxides) and chlorine are absorbed in a silver spiral and the water and carbon dioxide in anhydrone and soda asbestos, respectively. The silver (as silver sulphate) and chlorine (as silver chloride) are determined by extracting the silver spiral with hot water and ammonium hydroxide, successively.

A Simple Apparatus for Determining the Fusion Temperature of Coal Ash. J. Hiles and J. K. Thompson. (Fuel in Science and Practice, 1941, vol. 20, Aug.-Sept., pp. 135-137). The authors describe a Silit-rod electric furnace for the determination of ashfusion temperatures using 1 in. "cones" in a reducing or an oxidising atmosphere. The apparatus is simpler than any previously suggested, and can be used with thermocouple control. The same furnace can be used with adapting rings of insulating firebrick to accommodate the tube of $\frac{7}{8}$ -in. bore for making carbon, hydrogen, sulphur and chlorine determinations by the method described by Belcher and Spooner (see preceding abstract).

A New Catalyst for the Kjeldahl Combustion of Coals. H. E. Crossley. (Fuel in Science and Practice, 1941, vol. 20, Aug.—Sept., pp. 144–146). The author describes his research on the Kjeldahl method of determining the nitrogen in coal using selenium as a catalyst and the electric furnace described by Ockelford (see

next abstract).

Apparatus for the Kjeldahl Determination of Nitrogen in Coal. C. W. G. Ockelford. (Fuel in Science and Practice, 1941, vol. 20, Aug.—Sept., pp. 139–143). The author gives constructional details of the electrically heated pot furnace referred to in Crossley's paper on a new catalyst for the Kjeldahl combustion of coals (see preceding

abstract), and also describes a compact distillation stand for use in connection with this method of determining nitrogen in coal.

Platinized Silica Gel as a Catalyst in Gas Analysis. K. A. Kobe and R. A. MacDonald. (Industrial and Engineering Chemistry, Analytical Edition, 1941, vol. 13, July, pp. 457–459). The authors have replaced the silica gel catalyst with 0·075% platinum described previously (see Journ. I. and S.I., 1938, No. I., p. 363 A) by a more active one containing 0·125% of platinum. They describe its use, in the place of the copper-oxide tube and combustion pipet, for the determination of hydrogen, carbon monoxide, hydrocarbons and nitrous oxide.

Routine Determination of Phosphorus and Sulphur in Coke. L. Silverman. (Industrial and Engineering Chemistry, Analytical Edition, 1941, vol. 13, Aug., pp. 524–525). The author gives details of the procedures for making phosphorus and sulphur determinations in coke by a nitric-acid/perchloric-acid digestion method with a mixture of potassium permanganate and potassium dichromate as a catalyst.

BOOK NOTICE

(Continued from pp. 40 A-41 A)

Institute of Petroleum. "Annual Reviews of Petroleum Technology." Vol. 6. ("Petroleum Technology in 1940.") F. H. Gardner. General Editor. 8vo. pp. 318. Birmingham, 1941: The Institute of Petroleum. (Price 11s.)

The complete record of research and development in the petroleum industry since 1939 is as yet unpublished, and must necessarily remain so under existing circumstances. Nevertheless, the record, so far as it is presented in the present volume, is one of substantial progress in the applications of science to a world-wide industry. Comparison with previous volumes in this series will draw attention to many omissions in the contents of the present volume and to differences in the sequence of chapters. The contents are as follows: Petroleum Geology, by A. I. Levorsen; Regional Geology and Development in the United States, by W. A. Ver Wiebe; Drilling and Development in U.S.A. Fields, by M. T. Archer and L. S. Dawson; Production Engineering, by G. H. Scott; Production, by L. W. Storms, jun.; Transportation and Storage, by A. C. Hartley; Natural Gas, Liquefied Petroleum Gases, and Natural Gasoline, by T. Hoffman; Chemical and Physical Refining, by T. G. Hunter; Cracking, by P. C. Keith, C. W. Nofsinger, J. V. Hightower and N. L. Dickinson; Alternative Fuels: (a) Low- and Medium-Temperature Carbonization, (b) Fuels Produced by Hydrogenation and Synthetic Processes, by W. H. Cadman; Motor Benzole, by W. H. Hoffert; Analysis and Testing, by A. Osborn; Gas, Diesel, and Fuel Oils, by C. H. Barton; Asphaltic Bitumen and Road Materials, by W. W. Goulston; Special Products, by F. H. Braybrook, E. S. Paice, and M. B. Wilson; Petroleum Literature in 1940, by B. M. H. Tripp; Petroleum Statistics, by S. J. Astbury; Lubricants and Lubrication, by H. L. West.

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FUEL

(Continued from pp. 44 A-46A)

Combustion Calculations by Graphical Methods—Coke-Oven Gas. A. L. Nicolai. (Combustion, 1941, vol. 13, Oct., pp. 39-42). A graphical method of determining the calorific value of coke-oven

gas, together with an example, is given.

Combustion of Gaseous Fuels. F. E. Vandaveer. (Journal of the Western Society of Engineers, 1941, vol. 46, June, pp. 116–123). The author reviews the development of the use of gaseous fuels and outlines some of the research work which has been done

in the American Gas Association Testing Laboratories.

Preparation of Small Coal. (Iron and Coal Trades Review, 1941, vol. 143, Dec. 5, pp. 531–532). An illustrated description is given of a coal-cleaning plant recently erected at a Midland colliery. It comprises washing and classifying equipment, together with water clarification and slurry-recovery plant for controlling the density of the washing water at the desired optimum point to give the best washing results.

Process Statistics in the Operation of Coke-Ovens. H. Euler. (Archiv für das Eisenhuttenwesen, 1941, vol. 14, Feb., pp. 415–420). The author proposes standard methods for the presentation of statistics relative to coke-oven operation, and discusses their application for determining the efficiency of the operations and for

making comparisons between different plants.

Remarks Concerning the Pressure Developed during Carbonisation in By-Product Ovens. W. Fuchs. (Fuel in Science and Practice, 1941, vol. 20, Oct.-Nov., p. 161). In this article the author replies to some criticisms of his recent paper before the Franklin Institute. (See Journ. I. and S.I., 1941, No. II., p. 2 A).

Coke Quality and the Working of Blast-Furnaces. A. S. Bruk. (Iron and Steel Institute, 1941, Translation Series, No. 50). An English translation of a paper which appeared in Koks i Khimiya, 1939, No. 10–11, pp. 7–9. (See Journ. I. and S.I., 1940, No. II.,

р. 134 а).

A New Method of Evaluating the Physico-Mechanical Properties of Coke. N. S. Gryaznov and T. G. Zyryanova. (Iron and Steel Institute, 1941, Translation Series, No. 55). An English translation of a paper which was published in Koks i Khimiya, 1939, No. 10-11, pp. 9-13. (See Journ. I. and S.I., 1940, No. II., p. 134 A).

The Present State of the Production and Application of Fuel Gas from Lignite in the Steel, Malleable-Iron and Grey-Iron Foundry. V. Unger. (Giesserei, 1941, vol. 28, Apr. 4, pp. 150–156). After a general review of the production and properties of fuel gas derived from lignite, the author discusses its application for the heating of

metallurgical furnaces, with special consideration to foundry furnaces.

PRODUCTION OF IRON

(Continued from pp. 46 A-47 A)

Scale Cars for Blast-Furnace Stockhouse Service. E. W. Schellentrager. (Steel, 1941, vol. 109, Oct. 13, pp. 134–139). The author describes and illustrates a number of ore and coke transport cars with automatic weighing mechanism for transporting blast-furnace raw materials from the stock-house to the skip-hoist. With the latest design, the car carries two skip-buckets which are filled at the stock-house, weighed, moved to the furnace, and raised by the hoist direct from the car to the top of the furnace.

Desulphurisation of Pig-Iron. W. Eichholz and G. Behrendt. (Foundry Trade Journal, 1941, vol. 65, Dec. 11, pp. 379–380). An abridged English translation is presented of a paper which appeared in Stahl und Eisen, 1940, vol. 60, Aug. 1, pp. 677–683.

(See Journ. I. and S.I., 1941, No. II., p. 69 A).

Present-Day Wrought-Iron Production Practice. M. M. Karnaukhov. (Iron and Steel Institute, 1941, Translation Series, No. 46). An English translation of a paper which appeared in Metallurg, 1940, No. 2, pp. 16–20. (See Journ. I. and S.I., 1941, No. II.,

p. 69 A).

Powder Metallurgists Debate Techniques. (Iron Age, 1941, vol. 148, Oct. 30, pp. 29–35, 100). A report is presented of the proceedings at the Second Powder Metallurgy Conference held at the Massachusetts Institute of Technology on September 25 and 26, 1941. Thirteen papers were read, and these gave detailed information on manufacturing and processing methods, and on new applications in the field of powder metallurgy.

Russian Iron and Steel Industries in War-Time. (Iron and Steel, 1941, vol. 15, Nov. 10, pp. 57–60). A brief review is presented of the iron-ore resources, the geography of the industrial areas and the production capacity of the iron and steel industry

of Soviet Russia.

FOUNDRY PRACTICE

(Continued from pp. 48 A-49 A)

Recent American Developments in Cast Iron. A. B. Everest. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 65, Dec. 4, pp. 359–361). The author reviews American literature from 1939 to the present time on recent developments

in the production of iron castings. A bibliography with 31 refer

ences is appended.

Electric Heating in the Foundry. F. Knoops. (Giesserei, 1941, vol. 28, Apr. 18, pp. 179–181). After an elementary review of the advantages of electric heating and of various types of electric furnaces, the author gives some hints regarding the installation of

electric furnaces in the foundry.

Foundry Control Methods in Making Uniform Cast Iron. E. K. Smith. (American Foundryman, 1941, vol. 3, Aug., pp. 5–10; Sept., pp. 15–17, Oct., pp. 12–15). The author makes recommendations for the control of the raw materials charged in a cupola and for controlling the amount of moisture in the blast. Several forms of chill test and methods of controlling the structure by making ladle additions of ferro-silicon, ferro-chromium or a graphitiser are described.

A University Course in Foundry Control Methods. F. Holtby and H. F. Scobie. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Dec., pp. 310–321). The authors describe the subjects studied and some of the apparatus and equipment installed at the University of Minnesota for elementary and advanced courses in foundry work, and methods of control

and testing the materials used and the finished castings.

Practical Hints on Cupola Practice. A. Knickenberg. (Giesserei, 1941, vol. 28, Mar. 21, pp. 121-129). The author discusses modern cupola practice dealing in particular with the melting process, the lining of the cupola, charging and charging equipment, and composition of the charges for various types of castings. Summarising, he makes the following general recommendations: (1) The total cross-section of the tuveres should be about one tenth of the cupola cross-section. The best results are obtained with one row of tuyeres. (2) The layers of coke charged should be about 150 mm. high. For a charge containing 30% of steel the quantity of coke charged should be increased by 1%, which is the quantity required for carburising. (3) The amount of blast should be 140 to 200 cu. m. per min. per sq. m. and it must be adjusted according to the composition of the charge. (4) The pressure of the blast is determined automatically by the internal resistance of the cupola and the number and cross-section of the tuyeres. (5) The height of the bed-coke layer should be kept as constant as possible during melting, and the amount of blast and coke charged adjusted accordingly. (6) The coke should be covered with limestone, the addition of limestone amounting to at least 25% of the amount of coke in order to facilitate the reaction between slag and iron. (7) The blast should be reduced while blowing in and after completion of charging.

Rules for the Design of Grey Iron Castings. (Foundry Trade Journal, 1941, vol. 65, Dec. 18, p. 397). An English translation is presented of an official specification issued to German foundries in

1926 which comprises rules to be observed in the design of grey

iron castings.

Prevention of Wastage in the Design and Production of Malleable Iron Castings. F. Pristl. (Giesserei, 1941, vol. 28, Mar. 7, pp. 103–111; Mar. 21, pp. 129–132). The author discusses the factors which have to be taken into account in the design and production of black-heart and white-heart malleable iron castings. He first discusses the physical and mechanical properties of malleable cast iron and deals at some length with its structure. Particulars of the structural components are given in an extensive table, and numerous micrographs are reproduced. He also deals with the dimensions suitable for malleable iron castings, and with the preparation of the moulds, and the technique of casting, annealing and designs and designs an extensive tables.

ing and dressing.

The Kinetics of Graphitisation in White Cast Iron. H. A. Schwartz. (American Society for Metals, Oct., 1941, Preprint No. 27). After a historical review of the research on the graphitisation reaction during the last 115 years, the author reports on his study of the effects of the rates of dissociation, solution and linear crystallisation on the rate of the graphitisation process as a whole. He shows, by purely mathematical reasoning, that near the origin the graphite-time curve is determined by the rate of crystallisation of graphite or the rate of solution of cementite. When graphitisation is nearly complete, however, it is determined by dissociation. In the intermediate stages the migration rate or solution rate may become effective. He points out that, under the conditions usually prevailing, the rates of crystallisation or solution are effective for an almost negligible time interval only and a state succeeds which is conditioned by the migratory rate. The equations for the reactions involved are calculated in terms of fundamental properties, and the shifts along the time axis are also recorded in terms of such constants. The effect of temperature on these constants is taken into consideration. The author states that the results of the mathematical treatment of the subject largely confirm earlier empirical knowledge.

Steel Sand Mixtures Have Changed Little. H. Ramsey. (Foundry, 1941, vol. 69, Oct., pp. 61, 137–139). The author discusses the great variety of opinions prevailing among steel foundries as to what are the desirable properties of moulding sands. Methods of testing are considered, and as a means of checking sand mixes in a mill, the author suggests the installation of a recording wattmeter on the mill motor; this will respond to fluctuations in load

caused by the addition of water and binders.

Some Properties of Synthetically Bonded Steel Molding Sands. R. E. Morey and H. F. Taylor. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Dec., pp. 388–423). The authors studied the effect of changes in the grain size, shape and distribution of synthetically bonded moulding sands for steel cast-

ings on the physical properties of sand mixtures. Several clays were tested, and the green compressive strength of sands bonded with them were compared by plotting green-strength/water-content curves. Tests were also made using cereal binders of the cornflour

The Importance of the Hygroscopicity of Clay Binders for Moulding Sands. K. Endell, H. Reininger, H. Jensch and P. Csaki. (Giesserei, 1940, vol. 27, Nov. 29, pp. 465–475; Dec. 13, pp. 499– 502). The authors review the present knowledge of the nature of clay on the basis of the results of investigations with X-rays, the electron microscope and by colloid-chemical methods. An examination of the relation between the ability of clay binders to absorb water and the properties of synthetic moulding sands led to the following conclusions: (1) Bentonite is greatly superior to kaolin clays in binding power, and it therefore imparts a greater green and dry strength to sand; in fact, a small proportion of bentonite will give a strength to sand when the same proportion of a fatty, highly plastic kaolin clay would be insufficient to bind it, whilst at higher concentrations the strength of a bentonitebonded sand is three times as great. (2) The chemical nature of the exchangeable bases of the clay which determine its ability to absorb water demonstrates the superiority of the adsorbed sodium ions as compared with calcium ions. The greatest strength is obtained with sodium bentonites. (3) A comparison of the American natural sodium bentonite of Wyoming with the artificial German sodium bentonite (Geko) has shown that the German material gives a greatly superior green strength, whilst the dry strength obtained with the American bentonite is slightly superior to that obtained with the German product. (4) The earlier methods of judging the value of clay binders for moulding sand were completely inadequate. The properties which determine the usefulness of a clay binder are its mineral composition, its degree of dispersion, its base-exchange capacity, the nature and quantity of the cations forming its complex surface, and its behaviour in the hygroscopicity test in the Enslin apparatus. (5) Good cores, suitable for gassy melts, have been made with pure quartz sand and Geko.

The authors describe methods of determining these properties so

as to be able to classify clay binders in a scientific manner.

The Properties and Testing of Moulding Sands. H. A. Stephens. (Metals Institute of South Australia: Australasian Engineer, 1941, vol. 41, Sept. 8, pp. 10–11, 34–40; Oct. 7, pp. 12–13, 26). The author defines the various properties of moulding sands and shows how these are affected by changes in composition, grain size and methods of ramming. He describes a number of sand-testing appliances used for the standard tests of the American Foundrymen's Association and the British Cast Iron Research Association.

Silica Flour Controls Molding Sand. H. W. Dietert and G.

Curtis. (Foundry, 1941, vol. 69, Sept., pp. 58–59, 133–135; Oct., pp. 56–57). The authors discuss the effect of the addition of different proportions of silica flour on the properties of bentonite, clay-bonded sand and oil-bonded sand. The properties of mixtures at high temperatures and the relation between defects in castings such as cuts, blisters, hot tears and cracks, and the amount of silica flour added are dealt with.

The Use of Coal Dust in Moulding Sand. F. Naumann. (Giesserei, 1941, vol. 28, Jan. 10, pp. 10–12). The author discusses in an elementary way the effect of coal dust in moulding sand, and gives some hints regarding the quality and quantity required for

the preparation of suitable mixtures.

Pattern Equipment for Quantity Production of Small and Medium Castings. F. G. Butters. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 65, Dec. 18, pp. 391–394, 396). The author describes modern practice in the use of patterns made of wood, cast iron, brass, white metal and aluminium for the quantity production of small and medium castings. He discusses their advantages and limitations with different kinds of moulding machines.

Remarks on Gating Practice. R. Lehmann. (Giesserei, 1941, vol. 28, May 2, pp. 197–204). The author critically reviews present gating practice. He discusses various types of gates and risers, dealing especially with their arrangement, dimensions and relative widths, and makes suggestions for standardisation.

The Sphere of Application for Compressed-Air Moulding Machines. W. Caspary. (Giesserei, 1940, vol. 27, Nov. 15, pp. 446–450). The author describes and illustrates several types of German compressed-air moulding machines and discusses their advantages for

particular spheres of application.

Producing Marine Engine Castings. P. Dwyer. (Foundry, 1941, vol. 69, Sept., pp. 50–52, 129–132; Oct., pp. 58–60, 127–130). The author describes some of the moulding methods employed at an American foundry for casting the cylinders of large triple-

expansion marine engines.

The Use of Precast Paraffin Wax. H. Holdsworth and P. L. Ward. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 65, Dec. 11, p. 377). The authors describe the preparation of a mould for casting a tube-mill trunnion liner 4 ft. 9\frac{3}{4} in. long. A three-bladed feed-screw fitting inside one end was also part of the casting, and the pattern for this could not be withdrawn from the core. The difficulty was overcome by making the vanes of the screw of paraffin wax and leaving them in the core to melt out.

Briquetting Plant for Metal Swarf. (Engineering, 1941, vol. 152, Oct. 17, pp. 306–308; Nov. 7, pp. 366–368; Nov. 28, pp. 426–427). An illustrated description is given of a plant for the briquetting of three classes of swarf—namely, light-alloy swarfs, heavy non-

ferrous swarf and cast-iron swarf. The standard plant in question is capable of producing 8–12 cwt. per hr. of briquettes from lightalloy material and 10–20 cwt. per hr. from heavy material. This equipment is intended for use at foundries handling large quantities of this class of material. Some particulars of the cost of briquetting and the economic advantages of charging briquettes into cupolas are given. Another machine for briquetting steel swarf is also described.

Salvage and Disposal of Foundry Waste. W. Y. Buchanan. (Institute of British Foundrymen: Foundry Trade Journal, 1941, vol. 65, Nov. 27, pp. 343–345, 350). The author describes methods which have been adopted in different foundries for recovering and disposing of waste material in foundries. The materials dealt with include coke and metal from "cupola drop," material from roofs and dust-catchers, used core sand and moulding sand, and slag. Particulars are given of the design of a raised hopper with a ground clearance of about 8 ft. which holds about 80 tons of slag and refuse; this material is very difficult to shovel and throw up on to carts or lorries, and the hopper described is a solution to this problem.

Conveyor Belts for Foundries. H. Schulze-Manitius. (Giesserei, 1941, vol. 28, Feb. 21, pp. 73–78). The author emphasises the value of the installation of conveyor belts in foundries for the transportation of sand, coke and small castings, and gives a general review of various modern types of conveyor belts and their con-

struction.

The Iron-Carbon System and its Effect on Castings. J. W. Juppenlatz. (Reading (U.S.A.) Foundrymen's Association: Foundry, 1941, vol. 69, July, pp. 104–106; Oct., pp. 113–116). The author explains phenomena observed by the practical foundryman by reference to the iron-carbon diagram. It is seen, for example, from the diagram that the solidification temperature range widens as the percentage of carbon decreases from the eutectic point. As the amount of shrinkage which takes place increases as this range widens, it follows that larger risers will be required for eastings as

the carbon content of the iron decreases.

The Mechanism of Pin-Hole Formation. C. E. Sims and C. A. Zapffe. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Dec., pp. 255–269). The authors studied the causes of pin-hole formation in steel castings and came to the conclusion that hydrogen is mainly responsible for this phenomenon. They discuss various theories of the causes of pin-holes and explain why they do not accept the suggestion that they are formed by the evolution of carbon monoxide from the reaction of carbon with ferrous oxide, but favour the view that they have their origin in the formation of steam from the reaction of hydrogen with ferrous oxide and that they grow by hydrogen coming out of solution.

Causes of Changes in Dimensions of Castings and Means for Their Prevention. F. Naumann. (Giesserei, 1941, vol. 28, Feb. 21, pp. 78–81). The author enumerates the following factors to which non-uniform dimensions of castings may be due and suggests means for their elimination: (1) Swelling of the moulds; (2) feeding of the castings; (3) distortion of the castings owing to irregular shrinkage; (4) careless withdrawal of patterns; (5) patched moulds; (6) dimensional changes during the drying process; (7) unskilled blacking of the moulds; and (8) distortion of the patterns due to temperature effects.

Classification of Foundry Cost Factors. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Dec., pp. 282–309). This paper constitutes a report by the Cost Committee of the American Foundrymen's Association presented in the form of tables in which the numerous factors contributing to foundry costs for castings in grey iron, malleable cast iron, steel and nonferrous melts are classified under the headings of melting, mould-

ing, core making and miscellaneous costs.

PRODUCTION OF STEEL

(Continued from pp. 50 A-55 A)

Control of Steel Composition and the Problem it Presents. E. C. Smith. (American Iron and Steel Institute: Industrial Heating, 1940, vol. 7, Dec., pp. 1190–1194, 1199; 1941, vol. 8, Feb., p. 175; Mar., pp. 280-282; Apr., pp. 384-388; May, pp. 514-520; June, pp. 630-632, 663; July, pp. 754-760). In the first part of this paper the necessity of standardising commercial steel compositions and the difficulty of formulating specifications are emphasised. Brief particulars of the acid and basic open-hearth, the Bessemer and the electric-furnace processes are given in the second and third parts. In the fourth part the distribution of impurities in ingots in relation to the cooling rate, the ingot size and the de-oxidation process are discussed. The fifth part deals with drawing up specifications, and suggestions for the simplication of specifications are made. In the sixth part the procedure for obtaining representative samples of steel for chemical analysis is discussed. In the seventh and concluding part the maximum and minimum limits of possible carbon contents in alloy steel specifications are considered.

Modern Contributions of Titanium to Steel Production. (Steel, 1941, vol. 109, Nov. 3, pp. 96, 110, 111). Some general information is given on the use of titanium for deoxidising steel, and it is stated that titanium is also being used as an alloying element in stainless and 5%-chromium steels. For 18/8 steel the titanium content is at least four times the carbon content, and it prevents the formation of chromium carbide at the grain boundaries—a formation which renders the steel sensitive to intercrystalline corrosion.

Open-Hearth Slag Control during Melting by Rapid Chemical Determinations of Ferrous Oxide, Manganous Oxide, Lime and Silica. E. Maurer. (Iron and Steel Institute, 1941, Translation Series, No. 53). An English translation of an article which appeared in Stahl und Eisen, 1940, vol. 60, May 2, pp. 391-392. (See Journ.

I. and S.I., 1941, No. II., p. 119 A).

The Solubility of Iron Oxide in Liquid Iron. J. Chipman and K. L. Fetters. (American Society for Metals, Oct., 1941, Preprint No. 54). The authors determined the solubility of oxygen in iron under slags consisting mainly of iron oxides. For this purpose they developed a new method for the study of slag-metal equilibria. The method utilises inductive heating, which causes rapid stirring at the slag-metal interface, while the slag-gas interface remains relatively quiet. The oxygen content of the metal and the ferricoxide content of the bulk of the slag proved to be largely independent of the oxidising or reducing character of the gas atmosphere. The oxygen content of the molten metal was found to be not greatly affected by the purity of the iron-oxide slag in the range of 91% to 96.5% total ferric oxide. Further, they found that the oxygen content of molten iron in equilibrium with ironoxide slags is considerably lower than hitherto accepted and conforms approximately with the following equation:

 $\log \text{ oxygen percentage} = -4860/T + 1.935.$

Finally the authors studied the extent of the reduction of ferric oxide in contact with liquid iron. They found that an equilibrium condition is reached in which the ratio (%Fe₂O₃)/(%FeO) is about 0.07 at the melting point, decreasing with rising temperature to about 0.03 at 1800° C.

Electric Furnace Melting. A. G. Gierach. (American Foundry man, 1941, vol. 3, Aug., pp. 13-15; Sept., pp. 12-14). In the first part of this paper the author describes the development of the electric furnace and gives some information on the preparation of acid and basic electric-furnace linings. The importance of slowly drying out the brickwork is stressed, and it is stated that about 8-10 hr. are required to bring a 3-ton furnace up to the temperature at which burning-in may begin. For a basic bottom, magnesite or magnesite and dolomite, together with hot tar, or magnesite with which about 8% of finely ground clay has been intimately mixed, are commonly used for ramming. For acid bottoms, sand or ganister with proportions of fireclay and molasses are widely used. In the second part methods of charging and the melting, slagging and refining procedures are discussed.

Hydrogen Equilibria in Steelmaking. P. Herasymenko and P. Dombrowski. (Iron and Steel Institute, 1941, Translation Series, No. 45). An English translation of an article which appeared in Archiv für das Eisenhüttenwesen, 1940, vol. 14, Sept., pp. 109-

115. (See Journ. I. and S.I., 1941, No. II., p. 200 A).

Theory of the Absorption of Hydrogen in the Electric Furnace Melting of Steel. N. M. Chuyko. (Iron and Steel Institute, 1941, Translation Series, No. 47). An English translation of a paper which appeared in Teoriya i Praktika Metallurgii, 1938, No. 5,

pp. 31–37.

An Investigation to Improve the Life of Ingot Moulds. A. Ristow. (Iron and Steel Institute, 1941, Translation Series, No. 52). An English translation of a report which appeared in Stahl und Eisen, 1940, vol. 60, May 9, pp. 401–404; May 16, pp. 427–429. (See Journ. I. and S.I., 1941, No. II., p. 120 A).

FORGING, STAMPING AND DRAWING

(Continued from pp. 55 A-56 A)

Determination of the Resistance to Deformation in Dynamic Upsetting and of the Coefficient of External Friction for Several Structural Steels. K. Ginzburg and N. Ul'man. (Iron and Steel Institute, 1941, Translation Series, No. 42). An English translation of a paper which appeared in Stal, 1939, No. 6, pp. 26–28. (See

Journ. I. and S.I., 1940, No. I., p. 138 A).

Stresses and Flow of Material in the Drawing of Tubes. E. Siebel and E. Weber. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Feb., pp. 363–368). The authors study the distribution of stresses arising when drawing or pushing tubes through dies and forcing them over mandrels, and show that, generally speaking, only slight changes in the wall thickness occur when drawing tubes through a die or pushing over a mandrel, but considerable changes in thickness occur when tubes are drawn over a mandrel or pushed through a die.

Problems in the Drawability of Deep Drawing Sheets. M. Asimow and J. N. Crombie. (American Society for Metals, Oct., 1941, Preprint No. 7). The authors discuss many factors involved in deep-drawing steel sheet and review several test procedures for evaluating the deep-drawing properties, pointing out how these fail to predict the results of drawing operations at industrial plant. They find that fracture in drawing is dependent upon the relative multi-axial stress conditions and on the amount of strain-hardening the metal has undergone, and advance a hypothesis which suggests the general conditions under which rupture may be expected to occur. A bibliography with 248 references is appended.

20,000 Lb. Drop Hammer Installed for Production of Armament Forgings. (Heat Treating and Forging, 1941, vol. 27, Sept., pp. 457–458). An illustrated description is given of a large steamhammer recently installed at a works in Chicago for making arma-

ment forgings.

Application of High-Frequency Induction Heating to Shell Forging. (Machinery, 1941, vol. 59, Nov. 27, pp. 233–235). Some particulars are given of two high-frequency induction-heating machines designed to heat short lengths of seamless steel tubing so that one end can be swaged and closed to form the base, and the other end heated for shaping into the nose of the shell.

Stamping Trends in the Aircraft Industry. J. H. Engel. (Heat Treating and Forging, 1941, vol. 27, Sept., pp. 462–466). The author discusses the stamping of heavy steel sheet and of thick aluminium alloy parts for heavy aircraft with particular reference to "stage dies" for drop hammers which are the dies used when there are several intermediate stages of stamping before the final shape is produced.

Die Construction: Open Calibers. P. Patek. (Heat Treating and Forging, 1941, vol. 27, Sept., pp. 455–456). The author presents and explains a formula for calculating the radii of dies

used for forging round bars down to smaller diameters.

PYROMETRY

(Continued from pp. 18-A-19 A)

Third Report of the Liquid Steel Temperature Sub-Committee of the Committee on the Heterogeneity of Steel Ingots. (Iron and Steel Institute, 1942, this Journal, Section I.). The Report covers the work carried out in Sheffield during the last two years with the quick-immersion technique for measuring the temperature of liquid steel by means of a platinum thermocouple.

The Report is divided into two Sections. In the first, the Sub-Committee present some general comments on the design of the quick-immersion thermocouple, on temperature distribution and control in the furnace and in the ladle, and on emissivity and optical pyrometry, based on the data presented in more detail in the second Section; in conclusion, an outline of the Sub-Committee's

programme of research is given.

Section II., by Dr. F. H. Schofield, is an account of recent experimental work carried out with the quick-immersion thermocouple in several steelworks in Sheffield. It is sub-divided into three parts. In Part A, a number of suggested improvements in the mounting of thermocouples for employment in open-hearth, are and high-frequency furnaces, with a few points connected with their use, are described. Part B deals with special applications of the instrument—for example, (a) determining the temperature distribution in large and small are furnaces; (b) the comparison of the thermocouple and an optical pyrometer on an open-hearth furnace, showing that only during the boil does the latter give even approximately the temperature of the steel; (c) the determination, by

means of the thermocouple, of the accuracy of two types of optical pyrometer when sighted on a stream of steel, namely, the disappearing-filament pyrometer and a new "colour" pyrometer, in which the inferiority of the latter is clearly established; and (d) measurements in the trough, showing the remarkable constancy in temperature of the outflowing metal during the half-hour required for the casting from a 25-ton ladle. In Part C the position at several works with regard to the exercise of temperature control, on the basis of the thermocouple, is dealt with, showing that a definite routine is now in operation in many of the smaller furnaces, and that good results have already been obtained in some of the larger.

Rapid Temperature Measurements of Molten Iron and Steel with an Immersion Thermocouple. F. Holtby. (American Society for Metals, Oct., 1941, Preprint No. 55). The author developed a new type of tungsten-graphite immersion thermocouple suitable for the measurement of the temperature of small amounts of iron and steel in the laboratory. The construction, calibration and operation of the thermocouple are described, and the author states that temperature measurements can be made in 10 sec. and without causing any contamination of the molten metal. Whilst the e.m.f. at cold-junction temperature is small, it becomes relatively high (about 30 mV.) in the temperature range of molten iron and steel.

Further Considerations Relating to a Proposed New Type of Pyrometer for Measuring Gas Temperatures. R. H. Rowse. (Journal of Scientific Instruments, 1941, vol. 18, Dec., pp. 240–242). Further consideration is given to a new type of pyrometer proposed by Blackie (see Journ. I. and S.I., 1941, No. II., p. 125 A). The results of a general mathematical analysis are given, together with tables giving an abbreviated list of sets of wire gauges which satisfy the problem of multi-thermocouples for measuring the true temperature of flowing gases with a single reading.

HEAT TREATMENT

(Continued from pp. 58 A-61 A)

Heat Treatment of Cast Iron. C. A. Nagler and R. L. Dowdell. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Dec., pp. 361–382). The authors describe their investigation of the changes in hardness and microstructure of two grey cast irons after submitting them to identical forms of heat treatment. The irons contained combined carbon 0·79–0·86% and graphitic carbon 2·11–2·27%; to one of these 0·98% of molybdenum was added. Pairs of specimens 1 in. long and 1 in. in dia. were prepared; some of these were heat-treated at 1600° F. and quenched in water at 60° F., and others were isothermally transformed by quenching from 1600° F. in salt baths held at various

temperatures with a final quench in water at 60° F. In addition, some pairs of specimens, after quenching from 1600° to 60° F., were tempered at successively higher temperatures up to 1300° F. The authors came to the following conclusions: (1) The transformation-temperature/hardness curves for irons when isothermally transformed are parallel over the temperature range 200–1300° F.; (2) conclusion (1) also applies to quenched and tempered specimens; (3) the addition of molybdenum retards the transformation of the austenite and increases the hardness of samples which have been treated for 1 hr. in the salt bath; and (4) the hardness of both cast irons is higher after quenching and tempering than after isothermal transformation at the same temperature and for the same time as applied in the tempering process.

Application of Oscillograph to Determination of Cooling Rates of Quenched Steels. C. R. Austin, R. M. Allen and W. G. Van Note. (American Society for Metals, Oct., 1941, Preprint No. 12). A full description with diagrams is given of an apparatus developed by the authors for obtaining recordings of the rapid cooling of quenched steels. The apparatus includes a gas-quenching unit, a thermocouple amplifier circuit, a low-frequency oscillograph and a recording camera. Some of the curves obtained are reproduced and discussed. In view of the special technique and problems involved in the application of a direct-current amplifier oscillograph unit, the exact procedure for conducting the experiments is

described in an appendix.

Study of Dimensional and Other Changes in Various Die Steels Due to Heat Treatment. G. M. Butler, jun. (American Society for Metals, Oct., 1941, Preprint No. 49). The author studied various popular die steels with regard to variations in length, magnetic saturation and hardness after heat treatment at various temperatures, and after tempering at 190° C. and lower temperatures. He found that the new air-hardening manganese-chromium-molybdenum steels could be treated so as to return exactly to their original lengths after tempering. Overheating or prolonged soaking caused shrinkage. Air-hardening high-carbon high-chromium steels showed only slight expansion, whilst oil-hardening high-carbon high-chromium steels expanded more than any of the other steels examined. Oil-hardening manganese steels expanded considerably on hardening but reverted to almost their initial length after tempering. The chromium-molybdenum steel examined (chromium 5%, molybdenum 1%) showed more expansion than any of the others except the oil-hardening high-carbon high-chromium steels. The length measurements were confirmed by three-dimensional measurements on blocks, an air-hardening manganese steel showing less distortion than an oil-hardening manganese steel and the 5%chromium 1%-molybdenum steel. The author found an intimate relationship between the change in length and the amount of retained austenite, as measured by magnetic saturation methods.

Minimum distortion proved to correspond to a critical proportion of austenite. In those steels which deformed least this proportion was attained by normal hardening. In the other steels overheating, undesirable in other respects, was necessary for the smallest change in length. Oil-quenching was applied also to some of the air-hardening steels, but it did not result in any marked advantage. The author showed the degree of austenite retention to be the controlling factor in the relative changes in length of the air-hardening steels. As more austenite was retained the expansion became less, until, with enough retained austenite, actual shrinkage took place. The degree of magnetic saturation, which was taken as a measure of the amount of retained austenite, correlated well with the expansion measurements.

Fundamental Features of Controlled Atmospheres, Particularly for the Heat Treatment of Steel. H. W. Gillett and B. W. Gonser. (American Society for Metals, Oct., 1941, Preprint No. 31). The authors discuss in an elementary way some causes of failure when using controlled atmospheres in the heat treatment of steel, and emphasise the importance of obtaining a gas mixture in true equi-

librium with steel.

Chemical Equilibrium as a Guide in the Control of Furnace Atmospheres—A Review of Equilibrium Data. J. B. Austin and M. J. Day. (American Society for Metals, Oct., 1941, Preprint No. 32). The concept of chemical equilibrium and the properties of the equilibrium constant are discussed in an elementary way, with particular regard to their importance in the control of conditioned atmospheres in metallurgical furnaces, and selected values are given of the equilibrium constants of some reactions of im-

portance in the production of iron and steel.

The Heat Treatment of the Chromium-Carbon Stainless Steels. W. E. Mahin and W. C. Troy. (American Society for Metals, Oct., 1941, Preprint No. 34). The authors applied the furnace and heat-treatment procedure suggested by Scott and Gier for tool steels (see Journ. I. and S.I., 1941, No. I., p. 16 A) to cutlery steels with 12% to 14% of chromium and 0.30% to 0.40% of carbon. In this way the formation of oxide films, to which these steels are particularly liable, could be impeded. They paid especial attention to the control of the hardness of the steels treated, and by adding 1% of natural gas, containing 85% of methane, to the hydrogennitrogen atmosphere used by Scott and Gier, they succeeded in producing a surface hardness of over 60 Rockwell C. In conclusion they enumerate various applications, in addition to that of cutlery material, for which the steels are suitable after the heat treatment suggested, laying special emphasis on the fact that they can easily be furnace-brazed.

The Heat Treatment of High-Speed Steel Form Tools. R. R. Dorling. (Machine Shop Magazine, 1941, vol. 2, Nov., pp. 98–103). In discussing the heat treatment of high-speed steel tools (tungsten

18%, chromium 4%, vanadium 1%, carbon 0.7%) the author makes the following recommendations: Tools of delicate section should be gradually heated to about 200° C., then put in the preheating zone of the heat-treatment muffle furnace and heated at a slow and uniform rate up to $850-900^{\circ}$ C., and finally heated rapidly up to $1300-1320^{\circ}$ C. The tools should then be quenched in oil or an air blast, given a secondary heat treatment at $550-600^{\circ}$ C. for 1-2 hr. and allowed to cool in still air.

Surface Effects Accompanying the Heating of Carbon Tool Steel in Oxidising Atmospheres. R. D. Stout and T. Aho. (American Society for Metals, Oct., 1941, Preprint No. 45). The author confirmed the finding of previous investigators that an increased carbon content of the steel surface can be obtained by heating in oxygen atmosphere. He also observed this phenomenon when using oxidising atmospheres free from carbon compounds, so that the carbon must have been supplied by the steel itself. He found a close relationship between the carburisation of the surface and the rate of scaling, high scaling rates causing a large increase in surface carbon and low rates leading to decarburisation. He showed by thermodynamic calculations that the phenomenon was not due to any equilibrium conditions, and suggests that the carburisation is governed by the rates of two reactions, viz.: (a) The rate of escape of carbon through the scale, which is limited by its low solubility and diffusion rate in that phase; and (b) the rate of oxidation of iron, i.e., the scaling rate. With high rates of scaling the iron is removed so rapidly that the greater part of the carbon is not eliminated but instead is forced back into the austenite; later, when scaling has slowed down, the outward diffusion of carbon overtakes the removal of iron and decarburisation results.

Methods for Determining the Degree of Carburisation or Decarburisation and Evaluating Controlled Atmospheres. N. K. Koebel. (American Society for Metals, Oct., 1941, Preprint No. 44). The author describes the following methods for determining the degree of carburisation or decarburisation achieved when heattreating steel: (1) Hardness tests, especially determination of the Rockwell C hardness; (2) photomicrographic examination; (3) chemical analysis of consecutive sections and (4) determinations of changes in weight. He describes the application of these methods in detail, and discusses in each case the accuracy of the results, sources of error, limitations, and advantages and disadvantages. The first two methods do not yield quantitative results, whereas the last two supply quantitative data and can, therefore, be used for comparing the effects on steel of annealing in various atmospheres and for evaluating the efficiency of controlled atmospheres.

Properties and Structures of Case Hardened Steels Affected by Cooling Practice after Carburizing. O. W. McMullan. (American Society for Metals, Oct., 1941, Preprint No. 29). In cases in which direct quenching is not suitable, carburised articles are in practice

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cooled down to, or near to, room temperature before reheating and quenching. The author studied the effect of this intermediate cooling on the physical properties of steel in order to find out whether it could be dispensed with; this would result in saving of time, retort space and fuel for reheating. The investigation was carried out with steel S.A.E. 4815, and the specimens were directquenched, cooled to 795° C. and quenched, or cooled to various temperatures before reheating to 795° C. with subsequent quenching. The specimens were subjected to Izod impact tests and bend tests, the results of which are tabulated in the paper. The former tests were not sensitive, whereas the latter proved to be most sensitive to changes in properties brought about by changes in the cooling cycle. These tests, and also subsequent microscopic examination, indicated that it is unnecessary to cool below the temperature at which the austenite grain size is broken up before reheating for hardening. For steel S.A.E. 4815 this temperature is between 550° and 480° C. This temperature appears to correspond to the nose of the S-curve, and the author assumes it to be similarly located for steels of other compositions.

Gas Carburizing Diesel Engine Parts. K. Presser. (Industrial Heating, 1941, vol. 8, Sept., pp. 964–968). The author describes a simple and efficient form of gas-carburising furnace for case-hardening camshafts and other parts for Diesel engines. The carburising gas for this furnace consists of a mixture of natural gas with the products of combustion of another gas from a retort.

2,000,000 Crankshafts without a Reject. (Iron Age, 1941, vol. 148, Nov. 6, p. 69). A brief description is given of an induction hardening unit for hardening the journals and crank-pins of tractor crankshafts. A high-frequency current at 2000 cycles per sec. is applied to the coils for $4\frac{1}{2}$ sec. after which the surfaces are quenched in water. The total heat-treatment time per shaft has thus been very greatly reduced and the hardness obtained is remarkably uniform.

The Working of Nitriding Steels. (Machinist, 1941, vol. 85, Dec. 20, pp. 875–886). A comprehensive description is given of the equipment and procedure for nitriding steel. The analyses and properties of steels suitable for nitriding are given as well as

recommendations on the machining of nitrided parts.

Urea Process for Nitriding Steels. R. P. Dunn, W. B. F. Mackay and R. L. Dowdell. (American Society for Metals, Oct., 1941, Preprint No. 26). The authors describe the apparatus and procedure they developed for nitriding steels with ammonia formed by heating urea at about 130° C., the specimens being held at 510° C., and present data on the hardness and depth of case obtained. Three types of steel were tested, namely, Nitralloy 135, S.A.E. 1020 and S.A.E. X1314. The results indicated that satisfactory hardness can be obtained by this process, and that with suitable revision of procedure and apparatus, the process has distinct commercial possibilities having regard to the low cost of urea.

New Batch-Type Furnace Provides Precise Heating-Cooling Cycles in the Annealing of Seamless Tubes. J. J. B. Rutherford and N. Hamilton. (Industrial Heating, 1941, vol. 8, Sept., pp. 974–984). The authors describe, with illustrations, two batch furnaces for annealing seamless alloy steel tubes in long lengths. (See Journ.

I. and S.I., 1941, No. II., p. 129 A).

The Tempering of Two High-Carbon High-Vanadium High-Speed Steels. B. S. Lement and M. Cohen. (American Society for Metals, Oct., 1941, Preprint No. 47). The authors studied the phenomena involved in the tempering of high-carbon high-vanadium high-speed steels by means of hardness, specific-volume, X-ray and dilatometric measurements. The investigation led to the following conclusions: (1) Hardened high-carbon high-vanadium high-speed steels, with and without tungsten, contain primary martensite, retained austenite, undissolved complex carbides and undissolved vanadium carbides, especially face-centred cubic VC. (2) The general mechanism of tempering is quite similar to that which takes place in 18/4/I tungsten-chromium-vanadium steel (see Journ. I. and S.I., 1940, No. I., p. 24 A); as in that steel, very little of the retained austenite transforms at the tempering temperature, the bulk of it transforming during cooling after tempering. (3) The amount of austenite which transforms during cooling depends on the extent of the cementite precipitation occurring at the tempering temperature. (4) The retained austenite may transform isothermally if cooling from the tempering temperature is stopped within the proper temperature range. (5) The total tempering time required to condition the retained austenite for complete transformation is practically independent of whether the tempering is carried out as a single or a repeated treatment. (6) With optimum tempering temperatures complete transformation of the retained austenite can be achieved in 2 to 2½ hr. (7) The response to tempering is the same for section sizes up to at least 1 in., provided that the time required by the specimen to reach uniform temperature is taken into consideration. (8) Tempering of the steels under examination should be carried out in two stages, the first treatment conditioning the austenite for transformation and the second serving as stress-relieving operation.

WELDING AND CUTTING

(Continued from pp. 61 A-62 A)

A Note on the Welding Without Preheating of Cast Irons of Various Qualities. G. Kritzler and G. Arnold. (Giesserei, 1941, vol. 28, Feb. 7, pp. 52–58). The authors point out that it would be desirable to be able to weld cast iron to steel and that they therefore studied, as a preliminary stage, the behaviour of cast iron on welding without preheating. They used three different

qualities of cast iron for the investigation, the analyses of which are listed in the paper, and carried out oxy-acetylene welding with cast-iron rods. They succeeded in welding simple cast-iron parts of not too great width. They recommend welding the first part of the seam with the "back-step" technique, and heating the surrounding material carefully, in the direction of the seam as well as at right angles to it. The possibility of shrinkage at right angles to the seam, as well as the change from contraction to expansion in the direction of the seam, have to be taken into account, however. The composition of the welding rod was found to be of decisive influence and the best results were obtained with rods of the following composition, melting at 1100° C.: Total carbon 3.18%, graphitic carbon 1.95%, silicon 4.00%, manganese 0.57%, phosphorus 0.59%, sulphur 0.081% and copper 0.06%. The composition of the base material and modifications in the welding technique had little effect on the quality of the weld.

A Brief Discussion on the Manufacture of Steel for Arc Welding Electrodes. C. W. Garrett. (Wire and Wire Products, 1941, vol. 16, Oct., pp. 559–564). The author correlates certain characteristics in the behaviour of welding electrodes (e.g., spatter and rate of melting) with the processes of steelmaking, rolling, heattreating and drawing the wire of which the electrodes are made. He points out that the structure is stabilised and the melting rate when welding is reduced by 30% reduction in cold-drawing. If the wire is subsequently normalised, this increases the melting rate

when welding by 30% to 100%.

The Problem of Welding Cast Steel. W. Schumacher. (Giesserei, 1940, vol. 27, Dec. 27, pp. 515–522). The author reports the results of hardness, elongation, impact and creep tests on welded specimens of cast carbon steel and cast molybdenum steel after various forms of heat treatment, the object being to determine the optimum heat treatment for castings with defects repaired by welding. It was found that, for both kinds of steel castings, after normalising and welding, it was necessary to apply a subsequent heat treatment at 600° C. followed by cooling in the furnace. In the case of cast molybdenum steel which is to be machined where it has been welded, the heat-treatment temperature should be raised to 750° C.

CLEANING AND PICKLING OF METALS

(Continued from pp. 28 A-29 A)

Profitable Uses for Stainless Steel by Electro-Polish Process. (Monthly Review of the American Electroplaters' Society, 1941, vol. 28, Mar., pp. 179–184). Brief details are given of an electrolytic process known as "Electro-polish" for polishing stainless-

steel articles. The procedure, initial cost of the equipment, and data on current densities are discussed.

European Munitions Cleaning Technique. M. Zinty. (Iron Age, 1941, vol. 148, Oct. 16, pp. 38–41; Oct. 23, pp. 31–35). The author reviews the practice adopted in munition works in Europe for the cleaning of shells and cases in the different stages of manufacture. In the first part flow-sheets of the materials through the various processes are shown and some cleaning machines for large sizes of shell, bombs and grenades are described. In the second part the methods of cleaning shell and cartridge cases and the smaller sizes of munitions are dealt with.

Regulations for Protection against Silicosis when Sand-Blasting in the Cleaning Department of a Foundry. G. Zweiling. (Giesserei, 1940, vol. 27, Sept. 20, pp. 362–365). The author discusses the regulations recently published by the German Ministry of Labour relating to the prevention of silicosis among workmen in the casting-

cleaning department of a foundry.

Bibliography on Blast Cleaning with Metallic Abrasives. R. Hopp. (Heat Treating and Forging, 1941, vol. 27, June, pp. 280, 289, 290; July, pp. 328–332). The author presents a bibliography of technical articles which have appeared in American, British, French and German journals on blast cleaning with metallic abrasives.

Surface Phenomena on a Stainless Cutlery Steel with a High Chromium Content. A. Pomp and W. Lueg. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 16, pp. 250–254). In this paper the authors report on their investigation of the causes and methods of preventing the formation of the pickling cracks revealed by hot-etching the 13.6%-chromium steel for knife blades referred to in their earlier work (see p. 64 A). The effect of the pickling time, the rate of cooling, subsequent heat treatment and the direction of rolling and deformation were examined, and a form of heat treatment was developed which prevented these cracks from appearing without lowering the mechanical properties of the steel.

COATING OF METALS

(Continued from pp. 30 A-32 A)

The Chrome-Hardening of Cylinder Bores. H. van der Horst. (Mechanical Engineering, 1941, vol. 63, July, pp. 536–539, 542). The author examines the causes of the wear of piston rings and Diesel-engine cylinders and compares the wear of nitrided and of chromium-plated cylinder bores. The properties of chromium coatings are discussed and it is shown that it is desirable to have

a porous coating which will hold oil rather than a dense and highly

polished surface.

"Hard" Chromium Plating—An Important Method for Extending Tool Life. J. T. Hyduke. (Steel, 1941, vol. 109, July 14, pp. 76-81). The author describes the plant and equipment at an American chromium-plating works which specialises in the hard plating of tool and dies and the building up of worn parts. Special reference is made to the design of the plating racks and the lead anodes.

Chrome Plating Saves Glassware Moulds. D. McGregor. (Machinist, 1941, vol. 85, Dec. 13, pp. 854–855). The author describes the correct technique for chromium-plating Mechanite

moulds for pressing bowls and other articles out of glass.

Cleaning and Bright Plating Iron and Steel Parts of Electric Irons. F. A. Maurer. (Monthly Review of the American Electroplaters' Society, 1941, Sept., pp. 695–707). The author gives a fairly detailed description of the sequence of cleaning, plating and polishing processes in the manufacture of electric irons. A theory for the mechanism of bright nickel plating is suggested; this is that the crystals of bright nickel are kept extremely small and uniform in size and that they develop on the surface in a definite orientation. The addition of an agent such as nickel naphthalene trisulphonate to keep the crystals under 0.0001 mm. is proposed.

Corronizing. R. Rimbach. (Monthly Review of the American Electroplaters' Society, 1941, July, pp. 533–538). The author gives brief particulars of a method of coating ferrous or non-ferrous metals which is known as "Corronizing." The process in its present state of development consists of applying thin composite coatings of nickel and zinc, or nickel and tin by electrolysis. After coating, the material is heat-treated at 500–750° F. for up to 6 hr., the exact conditions depending on the thickness of the base metal and the requirements of the finished material. It is claimed that Corronized coatings can be produced thinner than hot-dip coatings and have the same life and that the thickness of the coating can be

accurately controlled.

Ignition by Sparks from Aluminium Coated Metalwork. T. S. E. Thomas. (Iron and Coal Trades Review, 1941, vol. 143, Sept. 5, pp. 210–211). It has more than once been reported that sparks have been observed when steam pipes and steam-heated vessels coated with aluminium paint have been struck or scraped with a tool of steel, copper, bronze or brass. The possibility that such sparks might ignite gases or vapours has led to the matter being investigated by the Safety in Mines Research Board, and a report of the investigation is presented in this paper. The general conclusion reached was that the use of aluminium paint with a linseed oil, coal-tar or cellulose base does not give rise to any danger from sparks unless the metal is heated to 150° C. or higher after being painted. The spark effect can only be produced if the surface of

the steel is rusty before being aluminium-painted. It is suggested that the phenomenon is a miniature thermit reaction between the

flakes of aluminium and the particles of rust.

Relation of Galvanizing Bath Temperature to Iron Content of Dross. W. G. Imhoff. (Products Finishing, 1941, May, pp. 24–36). The author studied the factors affecting the formation of dross in hot-dip galvanising baths. It was observed that the iron content of the dross increases with rising temperature, also that the crystalline form of the dross changes at about 900° F. Good zinc can be separated from dross by vibration. Dross should not be sweated at high temperatures in order to recover the zinc, because the zinc thus obtained is high in iron, and, if it is put back in the galvanising pot, it will absorb more zinc, thus "dross makes dross." The correct iron content of dross is about 3.75%, and this composition corresponds to a bath temperature of about 860–870° F. The specific gravity of the dross increases with the temperature. For efficient galvanising every bath should have a temperature recording instrument and the temperature of the bath should never exceed 900° F.

The Effects of Microstructure on the Galvanizing Characteristics of Steel. R. W. Sandelin. (Wire and Wire Products, 1941, vol. 16, Oct., pp. 567-580). The author gives an account of his investigation of the effect of cold reduction, grain size and carburising treatment of low-carbon steel wire containing copper and up to 0.410% of silicon on the characteristics of the zinc coating after galvanising. His conclusions were as follows: (1) Cold deformation had no appreciable effect upon the appearance of the coatings for either low-silicon or high-silicon steels. (2) Low-silicon steel had a bright coating and high-silicon steel a dark grey coating, whether the grain size was fine or medium; coarse-grained steel, as obtained on prolonged annealing at high temperatures, caused the coating to be grey on steels which, when of normal grain size, would have a bright spangled coating, but this applied only to short immersion times. For long immersion times of 3 min. the coatings were bright but rough. Coarse grains had no marked effect on the appearance of the coating on high-silicon steel. (3) The coatings of specimens of low-carbon steel quenched in water from 1675° F. had the same appearance as those of unhardened specimens. (4) Carburising samples of high-silicon and low-silicon steel did not materially affect the appearance of the coating. (5) Carburised specimens hardened by quenching in water produced bright, shiny, smooth coatings after short and long immersions. This was the only treatment which produced bright coatings on any of the high-silicon samples. (6) Neither copper (up to 0.675%) nor manganese (up to 0.87%) in the steel affected the coating; silicon caused the coating to be grey, but with about 0.20-0.25% a brightening tendency was noted after long immersion; a high phosphorus content (0.086%) caused the coating to be grey. (7) Increasing the amount of cold deformation increased the coating weight. (8) Coarsening the grain increased the weight of the coating especially after a long immersion time of 3 min. (9) Quenching specimens in water made no difference to the coating weight. (10) Low-silicon steels when carburised showed no change in coating weight, but carburising the high-silicon steels increased the weight of the coating after 30 sec. immersion, and the increase was very marked indeed after 3 min. immersion. (11) Carburised and hardened samples were unique in showing very low coating weights for both 30-sec. and 3-min. immersions.

The Repair of Hot-Dip Galvanized Coatings. W. G. Imhoff. (American Metal Market: Products Finishing, 1940, Dec., pp. 46–48). The author gives some information on repairing defective spots and areas in zinc coatings which have been applied by the hot-dip process. The repair is made by applying a proprietary

pe wder to the defect and heating it with a welding torch.

The Rate of Formation of Tin-Iron Alloy during Hot-Dip Tinning as Measured by a Magnetic Method. A. U. Seybolt. (American Society for Metals, Oct., 1941, Preprint No. 22). The author describes a magnetic method for determining the thickness of the tin-iron alloy which is formed when tinning steel sheet by the hot-dip process. Samples of tinplate $3 \times \frac{3}{4}$ in. were inserted in a search-coil which was connected in opposition to a duplicate searchcoil containing a similar, but untinned, specimen. The searchcoils were placed in a solenoid and when a current was passed through this induced currents were set up in the search-coils. If the two specimens were of equal dimensions, the induced currents were balanced, but if one specimen was placed in a tin bath and some of the iron converted into FeSn₂, which is non-magnetic, the galvanometer in the circuit was deflected and the amount of the deflection varied with the amount of magnetic iron removed or the amount of FeSn, formed. By using a series of specimens each of which had been immersed in the tin bath for a different length of time, the rate of formation of FeSn, was studied. Curves for these rates for different bath temperatures are presented.

Electro-Tinning Using Sodium Stannate Bath. S. Baier. (Steel, 1941, vol. 109, Oct. 27, pp. 66–69, 86). The author describes in detail the procedure for electrolytic timplating using sodium stannate baths containing a little free caustic soda. Methods of ensuring that the tin is dissolved in the quadrivalent form are given as well as the analytical procedures for checking the free caustic soda and the tin concentration, and for detecting impurities such as

nitrates, antimony, arsenic and lead.

Tinplate and the Food Supply. E. G. Jones. (Liverpool Metallurgical Society: Chemistry and Industry, 1941, vol. 60, Dec. 6, pp. 855–858). The author gives a brief account of the history of food canning and discusses some results obtained by various investigators in their work on the causes of the discoloration of both the tin coating of a can and the food stored in it.

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How to Spray Stainless Steel. C. F. Benner. (Iron Age, 1941, vol. 148, July 17, pp. 56-59). An American company operating 400 hydraulic presses for making synthetic resin parts had trouble with the corrosion and pitting of the rams. To combat this a method of spraying with stainless steel was developed, a description of which is given in the present paper. As the bond between the base metal and the sprayed metal was strictly mechanical, the surface of the ram had to have grooves cut in it. The worn ram was turned down to remove all pits, a thread was then cut on it. The next step was a roughening operation which spreads out the ridges of the thread. The ram was then cleaned with an organic solvent, and was ready for spraying. A standard metallising gun fed with 11 gauge stainless-steel wire was used and the first passes were made at an angle of 45° to the work which was rotated; the metal was thus deposited under the edges of the dovetail. After several passes at 45° the surface was finally built up with the gun directed perpendicular to the work. The sprayed surface was built up to exceed the required finished diameter and the ram was finally ground to size.

Sprayed Coatings. (Machinist, 1941, vol. 85, Oct. 11, pp. 619–621). Two reference sheets are presented in which are tabulated defects in sprayed paint and enamel coatings and methods of

correcting them.

The Electric Schoop Process. H. Brand. (Giesserei, 1940, vol. 27, Oct. 18, pp. 409–410). The latest development of the Schoop metal spraying process is outlined, and a photograph is reproduced of the new type of spraying pistol used, in which the metal is melted in an electric arc at temperatures of about 4000° C. Special mention is made of the production of various moulds and matrices by the improved Schoop process and of the possibility of depositing zinc on steel as well as steel on light-metal castings.

A Note on Metal Spraying. M. U. Schoop. (Giesserei, 1941, vol. 28, Jan. 10, pp. 9-10). The author gives some more details regarding his metal spraying process (see preceding abstract). He observed that coatings prepared from ordinary iron wires are not liable to rust, which is likely to be due to a nitriding reaction

taking place as the spraying proceeds.

Cause of Pinholes and Some Related Defects in Enamel Coatings on Cast Iron. C. A. Zapffe and C. E. Sims. (Journal of the American Ceramic Society, 1941, vol. 24, Aug., pp. 249–253). The authors report on an investigation of the causes of pinholes and other defects in vitreous enamel coatings on cast iron. It was observed that the occurrence of defects depended solely on the quantity of hydrogen in the iron. Iron may absorb hydrogen from moisture in the atmosphere, from scrap in the charge during melting and from organic materials in the mould during casting. Hydrogen in molten iron may be removed satisfactorily by bubbling dry nitrogen through the melt before casting, but care must be taken to prevent any subsequent absorption of hydrogen before the enamel is applied.

Protective Painting of Structural Steel. (Iron and Steel Institute, 1942, this Journal, Section I.). In this paper, which was prepared by the Protective Coatings Sub-Committee of the Corrosion Committee (a Joint Committee of The Iron and Steel Institute and The British Iron and Steel Federation), an attempt is made to set out simply the facts concerning the best methods of protecting structural iron and steel work by means of paint. The choice of paint and painting procedures are discussed, but most emphasis is laid on the effect of the surface condition and pretreatment before painting, which are the most important factors determining success.

The following conclusions are drawn: (1) Maximum durability is achieved by painting over a surface that has been completely freed from mill scale and rust. (2) It is detrimental to allow a surface to rust again between the removal of the mill scale and rust and the application of the paint. (3) Painting over a complete film of mill scale may give good durability in some cases. (4) The life of paint applied to a surface from which mill scale and rust have

been incompletely removed is materially reduced.

The following practical recommendations are made: (1) Obtain a good surface free from mill scale and rust. This is best done by pickling, sand-blasting or shot-blasting. (2) Paint the surface immediately after it has been prepared. (3) Use a corrosion-inhibiting priming paint, such as red lead. Follow this with good weather-resisting finishing coats, such as oxide-of-iron or white-lead paints. (4) Apply all paints under good conditions.

If the painting of new iron and steel structures is carried out with due consideration to the principles outlined above, the saving in maintenance will more than repay the costs of surface preparation

before painting.

Mechanical Application of Bituminous Pipe Coatings and Linings. L. E. Goit. (Journal of the American Water Works Association, 1941, vol. 33, Oct., pp. 1723–1750). The author describes several different types of plant and equipment used for coating cast-iron and steel water-pipes internally and externally with bituminous tars and pitch. The internal coatings are applied by the centrifugal process. Many illustrations are given of the plant

used by the Los Angeles waterworks.

Silicon Aerogel as a Flatting Agent for Protective Coatings. J. F. White and I. V. Wilson. (Industrial and Engineering Chemistry, Industrial Edition, 1941, vol. 33, Sept., pp. 1169–1173). The authors describe the preparation and properties of silica aerogel and its effect on the properties of protective coatings. In the final drying stage in the preparation of silica gel great shrinkage takes place, which is due to the formation of a gas-liquid interface within the structure, and to the surface-tension forces at this interface. In making silica aerogel the formation of this interface is prevented by heating the gel under a pressure in excess of the critical pressure

of the liquid phase to a temperature above the critical point. Data are presented on the transparence, plasticity, flatness and strength of protective films containing silica aerogel.

PROPERTIES AND TESTS

(Continued from pp. 62 A-69 A)

International Comparative Tests and the Question of Standardisation. R. Bertschinger. (Giesserei, 1941, vol. 28, Jan. 24, pp. 25-34). The author reports on the results of an international investigation which was carried out, at the instigation of the Technische Hauptausschuss für das Giessereiwesen, from 1931 to 1935 by Alsatian, Belgian and German firms. Eleven qualities of cast iron were tested with regard to tensile strength, transverse strength, torsional strength, shear strength and hardness. The results obtained, which deviated relatively little, led to the following conclusions: (1) The tensile test is very suitable as a basic test for the classification of the materials. (2) The bend test is indispensable, unless very exact data obtained by tensile-compression tests are available. (3) There are relations between the shear strength, the torsional strength and the transverse strength on the one hand and the tensile strength on the other, which, under certain conditions, can be used for conversion of the values. In the second part of the paper the author briefly discusses the relation between tensile strength and fatigue strength; and reviews English and American standard specifications for cast iron.

The Effect of Strain Rate upon the Tensile Impact Strength of Some Metals. E. R. Parker and Catharine Ferguson. (American Society for Metals, Oct., 1941, Preprint No. 35). The authors carried out high-velocity tensile-impact tests in the way described by H. C. Mann (see Journ., I. and S.I., 1937, No. I., p. 280 A), examining a number of ferrous and non-ferrous alloys. They determined the energy absorbed during fracture at high rates of stressing as well as the elongation at fracture and the reduction of area. Some tests were also conducted to determine the effect of the design of the specimen on the energy absorbed during fracture. The majority of the materials tested absorbed more energy at higher impact velocities. The authors state, however, that no general conclusions can be drawn regarding the effect of the rate

of stressing on the impact strength values.

Qualities of Gray Cast Iron. H. L. Campbell. (Iron Age, 1941, vol. 148, Nov. 6, pp. 66–68). The author discusses the A.S.T.M. standard specifications for tensile tests on grey iron castings and gives details of a form of specimen holder which ensures that the stress is applied only in the axial direction.

The Tensile Properties of Pearlite, Bainite and Spheroidite. M. Gensamer, E. B. Pearsall, W. S. Pellini and J. R. Low jun. (American Society for Metals, Oct., 1941, Preprint No. 19). This paper is the second of a series dealing with the quantitative correlation of the microstructures observed in metals and alloys with the mechanical properties of these structures (see Journ. I. and S.I., 1940, No. I., p. 48 A). The authors determined the tensile properties of four steels (carbon 0.56-0.80%) and related these to the dimensions of the different structures formed in the material after special heat treatment. For the spheroidised samples, the mean uninterrupted straight path through the ferrite was measured, and for the pearlite the mean interlamellar spacing was determined. The pearlite spacing was shown to be proportional to the coefficient of carbon diffusion in austenite. It was found that the factors which determine the mechanical properties of aggregates consisting of a soft continuous phase and a hard dispersed one are the specific properties of the continuous phase and the mean length of uninterrupted path through the continuous phase, whether the structure be lamellar or spheroidal. The authors also established that the resistance to deformation varied linearly with the logarithm of the mean uninterrupted path through the continuous phase.

Effect of Pouring Temperature on the Strength and Microstructure of Gray Cast Iron. G. A. Timmons and V. A. Crosby. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Dec., pp. 225–251). The authors describe experiments which indicate that a reduction of the pouring temperature reduces the strength of cast irons of the high-test class, but produces relatively small changes in the tensile properties of irons of lower strength. The lower the pouring temperature, the greater is the tendency to form graphite distributions of the whorl, dendritic and eutectiform types, and the greater is the quantity of ferrite found in the microstructures of test bars. The changes in microstructures are correlated with changes in tensile properties for different pouring temperatures. The similarity of ferrite in grey iron, ferrite in chilled iron and the microstructure of box-cooled hypereutectoid

cases of carburised abnormal steels is discussed.

Low Temperature Impact Resistant Steel Castings. N. A. Ziegler and H. W. Northrup. (American Society for Metals, Oct., 1941, Preprint No. 37). The authors developed a low-alloy steel complying with the specification for steels used at extremely low temperatures for some chemical processes, which have to have a Charpy impact strength of at least 15 lb.-ft. at -100° C. The approximate composition was as follows: Carbon 0.05% max., silicon 0.20-0.50%, manganese 0.50-0.80%, sulphur 0.03% max., phosphorus 0.02% max. and nickel 3.5-4.0%. The following minimum values were obtained for the physical properties of this steel: Tensile strength 60,000 lb. per sq. in.; yield point 40,000 lb. per sq. in.; elongation at fracture 35%; reduction of area 60%;

and Charpy impact resistance at room temperature and at -115° C. 40 and 20 ft.-lb., respectively. High-grade raw materials, careful manufacturing technique and cleanness of the resulting product are essential for the successful production of this steel. Small amounts of carbide-forming elements, such as vanadium, chromium and molybdenum, may be added to improve the tensile strength, for these elements do not necessarily reduce the impact strength below

the minimum value specified.

Effect of Grain Size and Heat Treatment upon the Impact Toughness at Low Temperatures of Medium Carbon Forging Steel. S. J. Rosenberg and D. H. Gagon. (American Society for Metals, Oct., 1941, Preprint No. 36). The authors studied the effect of the grain size and of different heat treatments on the low-temperature impact strength of six heats of S.A.E. 1050 steel. Charpy impact tests, with standard V-notch specimens, were made at temperatures ranging from $+100^{\circ}$ to -78° C. The investigation led to the following conclusions: (1) S.A.E. 1050 steel, in the hot-rolled as well as in the normalised state, has a low impact strength. The hot-rolled steel is brittle at room temperature, the transition to cold brittleness occurring at temperatures above + 100° C. Normalising the hot-rolled steel improves the impact strength at room temperature and above, and the range of temperature at which cold brittleness occurs is lowered. (2) Differences in grain size in the normalised steels appear to exert some influence on the impact strength. The finer the McQuaid-Ehn or the normalised grain size the lower is the temperature at which cold brittleness is observed. This observation was not made with hot-rolled steels, however. (3) The impact strength is markedly improved by hardening and tempering, but normalising prior to heat treatment has no effect on this property. (4) High impact strength at room temperature is no criterion for high impact strength at low temperatures. (5) The impact strength of fine-grained steel is not necessarily greater than that of coarsergrained steel subjected to the same heat treatment. (6) Each individual heat of steel S.A.E. 1050 seems to have an inherent resistance to impact between certain limits, which are dependent on certain factors not yet recognised. (See also p. 63 A).

Photo-Elasticity and Magnetic Testing of Materials. R. V. Baud. (Schweizer Archiv für angewandte Wissenschaft und Technik, 1941, vol. 7, Aug., pp. 239–243). The author discusses the general principles of stress determination by photo-elastic and magnetic methods and their respective spheres of application.

The Temperature and Manner of Growth of Shatter Cracks in Steel Rails. H. B. Wishart, E. P. Epler and R. E. Cramer. (American Society for Metals, Oct., 1941, Preprint No. 52). The authors studied the formation of shatter cracks in rails of 131-lb. per yard, rolled from ingots treated with hydrogen. The investigation led to the following conclusions: (1) Shatter cracks develop

gradually, both in size and number, in "shatter sensitive" carbon steel rails during cooling in the range between 205° and 21° C. The temperature at which shatter cracks are first observed depends on the manner in which the rails are cooled through this range. (2) The formation of shatter cracks continues after the rails have reached room temperature. (3) Conclusions (1) and (2) apply only to shatter-sensitive air-cooled rails the cooling of which was not controlled and to rails which were not held at temperatures between 650° and 205° C. sufficiently long for the complete elimination of shatter sensitivity. (4) The temperature at which shatter cracks begin to form and the extent of retarded cooling required to prevent their formation depend on the susceptibility of the steel to develop shatter cracks.

An Elementary Theory on Fatigue Strength. T. Pöschl. (Iron and Steel Institute, 1941, Translation Series, No. 62). An English translation of a paper which appeared in Ingenieur-Archiv, 1941, vol. 12, Apr., pp. 71–76, in which the author develops an equation of motion for the oscillation process produced in a springy material by a periodic impressed force. This is a form of the equation valid for a simple oscillator, but shortened by the omission of the inertia

term.

The Bending-Fatigue Strength of Molybdenum- and Nickel-Bearing Structural Steels. A. Pomp and M. Hempel. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Feb., pp. 403–413). The results of a series of bending-fatigue tests on chromium-molybdenum steel, chromium-nickel steel and nickel steel are reported. (See

Journ. I. and S.I., 1941, No. II., p. 216 A).

Hardenability Testing of Low Carbon Steels. R. C. Frerichs and E. S. Rowland. (American Society for Metals, Oct., 1941, Preprint No. 16). The authors present and discuss the results of hardenability tests by six different methods on four grades of chromiumnickel-molybdenum steel containing carbon 0.20%. The types of test applied were: (1) Hardness surveys across cylindrical specimens quenched in a bath and in a spray; (2) the end-quench test after carburising; (3) the end-quench test before carburising; (4) the L-bar end-quench test; (5) the "bomb" test of McCleary and Wuerfel in which the specimens are heated in a bomb and quenched from 1500° F. in a water spray; and (6) hardness surveys along the surface of quenched tapered specimens. The authors are of the opinion that for rapid and accurate routine tests the Jominy end-quench test for high-alloy steels and the L-bar end-quench test for carbon and low-alloy carburising steels are the most suitable.

The Hardening Characteristics of an Iron-Cobalt-Tungsten Alloy. W. P. Sykes. (American Society for Metals, Oct., 1941, Preprint No. 50). The author studied the hardening characteristics of a ternary alloy containing 50% of iron, 30% of cobalt and 20% of tungsten, and compared the results with those obtained for the

binary iron-tungsten alloy of equivalent tungsten content. He found that the ternary alloy became progressively softer as the temperature of solution treatment was increased from 1100° to 1400° C., the hardness being considerably in excess of that found in the binary alloy, however. Air-cooling from temperatures of 1100° and 1200° C. resulted in greater hardness than water-quench-At an ageing temperature of 400° C, the hardness of the ternary alloy increased at a moderate rate, whereas the binary alloy required a temperature of 575° C. to harden in a comparable manner. In addition, no incubation period was required for the precipitation hardening of the ternary alloy at 400° C. The temperature of the solution treatment and the resulting concentration of tungsten in solid solution had little effect on the rate of hardening and the maximum hardness developed during ageing, although higher solution temperatures and correspondingly higher tungsten concentrations resulted in greatest resistance to softening during prolonged ageing at 600 and 700° C. The presence of retained austenite could not be established in any case.

Hardenability of Shallow Hardening Steels. C. B. Post, O. V. Greene and W. H. Fenstermacher. (American Society for Metals, Oct., 1941, Preprint No. 17). The authors describe a test which they developed for making quantitative measures of the hardenability of shallow-hardening steels. In this test the hardenability factor is the cooling rate in degrees Fahrenheit per second at which the steel must be cooled from 1300° F. to attain a 50%-martensite/50%-troostite structure. Various methods of determining this factor from sections of tapered specimens are described and correlations between the test data and those obtained by other harden-

ability tests are established.

The Spread of Brinell Hardness Determinations on Cast Iron. E. Pohl and H. Eisenwiener. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Feb., pp. 391-396). The authors report the results of an investigation organised by the Cast Iron Sub-Committee of the Verein deutscher Eisenhüttenleute in which Brinell hardness tests on cast iron were carried out by six different laboratories using a ball 10 mm, in dia, with a 3000-kg, load for 30 sec. The results were collated and possible causes of the spread of the data were examined. No relation could be established between the spread and the hardness in the range Brinell 120-180, nor was the spread found to depend upon characteristics of the instruments or the observers. When the hardness range was extended to Brinell 250, it was found that there was a marked change in the spread of the test data and that the structure also affected the results. spread, which was + 13 Brinell units when the mean reading was 120, was reduced to \pm 5 or 6 for a mean reading of 250. It was shown that the spread of hardness determinations on pearlitic cast iron was not dependent on the matrix, but on the quantity and form of the graphite. No definite relationship between the sum of the carbon and silicon contents, or the degree of saturation with

the spread of the hardness data could be established.

The Effect of Microstructure upon the Work-Hardening Characteristics of a 0.74 per cent. Carbon Strip Steel. N. P. Goss and W. Brenner jun. (American Society for Metals, Oct., 1941, Preprint No. 6). The authors report on an investigation they undertook to determine the effect of microstructure on the cold-rolling of specimens of 0.74% carbon steel strip which had been heat-treated to produce a sorbitic, a fine-grained pearlitic, or a spheroidised pearlitic structure, as well as the effect of subsequent heat treatment on the ductility and hardness. The conclusions reached were: (1) Sorbite work hardens more rapidly than spheroidised pearlite for reductions exceeding 70% in thickness; (2) spheroidised pearlite is more easily cold-rolled and does not develop edge cracks as readily as sorbite; (3) the plasticity of the pearlite is much greater than that of the sorbite; (4) sorbitic steel requires rolling with great care, especially in the reduction range of 5-20% and in excess of 70%; (5) after a final anneal the sorbite is more easily spheroidised; and (6) a final annealing produces a ductile structure of about the same hardness in both pearlitic and sorbitic steels.

Wear Tests on Ferrous Alloys. O. W. Ellis. (American Society for Metals, Oct., 1941, Preprint No. 5). The author describes an investigation of the wear of ferrous alloy balls in small ball mills. The importance of the effect of oxygen on the wear of carbon steel and chromium steel balls (chromium 15%, carbon 1–3%) is emphasised, for it was found that the value of chromium in conferring resistance to abrasion was lost in the absence of oxygen. The results of tests in a small sealed steel-lined mill indicated that chemical combination of iron and oxygen is the cause of much of the "iron loss" in mills, for it was observed that the pressure in the mill increased when nitrogen was the atmosphere and decreased when oxygen was the atmosphere within the mill. The conditions under which the abrasive effects of a Canadian sand on a series of iron-carbon alloys could be accelerated and diminished are

discussed.

Machinability vs. Microstructure of Aircraft Carburising Gear Steels. N. E. Woldman and R. G. Metzler. (American Gear Manufacturers Association: Iron Age, 1941, vol. 148, Nov. 6, pp. 59-64). The authors discuss the microstructure and machining properties of a 5%-nickel steel and a 1.5%-chromium 3.5%-nickel steel, and give details of the most suitable forms of heat treatment from the point of view of machinability and hardness when making aero-engine gears of these steels.

Dynamic Hardness Testing of Metals and Alloys at Elevated Temperatures. E. Fetz. (American Society for Metals, Oct., 1941, Preprint No. 38). In the first part of his paper the author reviews the European literature on dynamic hardness testers, with special reference to their applicability to metallurgical investigations

at high temperatures. The second part of the paper, which is based on the author's own investigations, represents the first American contribution to the literature on dynamic hardness testing at elevated temperatures. He used a guillotine type of testing machine described in detail in the paper, and applied it to the study of the following problems of practical interest: The effect of composition and heat treatment on the softening of die steels; the effect of increasing silicon additions on the hot-working properties of low- and high-carbon 18/8 steels; the effect of molybdenum on the softening characteristics of 12% chromium stainless steel; and the effect of rising temperature on the resistance to plastic deformation of 25/19 nickel-chromium steel.

Elimination of the Apparent Hot Brittleness of 0.50 Molybdenum Steel. C. L. Clark and J. W. Freeman. (American Society for Metals, Oct., 1941, Preprint No. 3). The authors present the results of long-time rupture tests on specimens of 0.50% molybdenum steels at temperatures in the 510-760° C. range. These show that this steel fails with a brittle fracture at certain temperatures, particularly 510° and 540° C. The effect of the addition of other alloying elements on the tensile properties of this steel is then considered, and it is shown that this hot-brittleness can be eliminated by the addition of chromium, or chromium plus silicon, but not by silicon alone. The addition of these elements also increases the tensile strength. The low ductility of this steel is believed to be associated with intergranular cracking, but intergranular fractures do not necessarily imply low ductility.

The Cyclic Temperature Acceleration of Strain in Heat Resisting Alloys. G. R. Brophy and D. E. Furman. (American Society for Metals, Oct., 1941, Preprint No. 24). The authors report on an investigation of the changes in the rate of strain of heat-resisting alloys under constant load at about 980° C. when the temperature is made to fluctuate. Specimens 39 in. long and $\frac{3}{8}$ in. in dia. with a 4-in. gauge length of 24/20, 18/8 and 18/10 chromium-nickel steel were tested. Extensometer tests were run at 980° C, under constant load for sufficient time to establish a fairly constant rate of extension. The temperature was lowered (usually to 870° C.) and then restored to 980° C., and readings of the extension were taken after the completed cycle. It was found that the change in temperature caused a marked acceleration of the creep rate, and the authors consider this to be due to a stress generated in the test-bar by reason of a transverse thermal gradient produced during the fairly rapid cooling. The creep rate was found to increase with increase in (a) the initial testing temperature, (b) the range of the temperature cycle, and (c) the applied load.

Investigation on the Suitability of Heat-Resistant Materials for Combustion Engines. Part III. H. Cornelius and W. Bungardt. (Iron and Steel Institute, 1941, Translation Series, No. 63). An English translation is presented of a paper published in Luftfahrt-1942-i

Forschung, 1941, vol. 18, Aug. 20, pp. 275–279, which is an account of an investigation of the creep strength in tension at temperatures between 600° and 1000° C. of twenty-two austenitic steels of industrial and special experimental quality. Data on the thermal expansion, specific gravity, modulus of elasticity, change of strength properties after annealing, and resistance to scaling are

given.

Young's Modulus and Recovery in Creep Tests. H. Esser and S. Eckardt. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Feb., pp. 397–401). The authors give an account of their investigation of the recovery of steel specimens after creep tests and how this is affected by the load, the duration of the load and the temperature. It was found that increasing the amount and duration of the load and the temperature all increased the degree of recovery, but with unalloyed steels and alloy steels with stable structures, the increase in the recovery was limited by the necking of the specimens. Steels with a tendency to become brittle attained a maximum degree of recovery after quite low loads. After the removal of small loads it is possible for the recovery to pass a maximum value, fall to zero and attain a negative value, i.e., the steel will creep again.

If a correction for permanent set after unloading is applied when calculating the Young's modulus, it must be borne in mind that above 300–400° C., according to the time which has elapsed, the amount of set will include a greater or less amount of recovery, and this can account for a considerable spread in the values obtained for the Young's modulus. The authors consider that in most cases the Young's moduli for high temperatures given in the literature

are too low.

The Rôle of Nitrogen in 18/8 Stainless Steel. H. W. Uhlig. (American Society for Metals, Oct., 1941, Preprint No. 23). The author prepared melts of 18/8 stainless steel under vacuum, as well as in air, nitrogen and hydrogen and studied the magnetic, mechanical, electrical and thermal properties of specimens from these melts with the object of determining the influence of nitrogen. The nitrogen-free 18/8 alloy quenched from 1150°C, is ferritic at room. temperature. Nitrogen, which is accidentally present in the commercial alloy, inhibits the $\gamma \longrightarrow \alpha$ transformation which occurs at about 100° C. on cooling. Several properties of the alloy are considerably different for the two lattice structures. In addition to the magnetic differences, the yield strength of ferritic 18/8 steel is 2.5 times that of austenitic 18/8 steel, and the Brinell hardness of the former is 1.7 times that of the latter. The electrical and thermal conductivities of the former are about 70% of those of the latter, and the coefficient of expansion below 500°C. of the ferritic steel is about 60% of that of the austenitic steel. The corrosion resistance of steels of the two lattice structures as determined by the loss in weight in ferric chloride, sodium chloride at 90° C., and in salt spray, is about the same for long-time heat-treated and for

water-quenched specimens. Under certain conditions nitrogen

diffuses readily into or out of 18/8 steel at 1150° C.

The Danger of Hair-Line Crack Formation due to the Taking-up of Hydrogen in the Course of the Manufacture of Steel. E. Houdremont and H. Schrader. (Stahl und Eisen, 1941, vol. 61, July 10, pp. 671-680). The authors studied the effect of inclusions and segregations on the tendency of steels to form hair-like cracks. They found that sulphidic inclusions have very little effect, whereas oxidic inclusions sometimes enhance the formation of hair-line cracks. The authors think this to be due to hydrogen contained in these inclusions and liberated at high temperatures. Segregated zones were found to behave like the surrounding material. Some information is also given regarding the effect of the alloy composition of the steels on their liability to hair-line crack formation, and the possible causes of this effect are discussed. The authors further report on their investigation of the effect of annealing in atmospheres containing either hydrogen compounds or hydrogen diluted with other gases, such as exhaust gas, illuminating gas, ammonia, water vapour and the gases developed by case-hardening compounds. They found that nearly as much hydrogen is taken up from such atmospheres as from the pure gas. From this finding they conclude that hydrogen may be taken up in practice during case-hardening or during heat treatment in gas-fired furnaces. The authors point out, however, that hydrogen penetrates relatively slowly into the steel, so that, with the limited annealing periods usual in practice, there is no danger of excessive taking-up of hydrogen by articles of large dimensions.

The Danger of Hair-Line Crack Formation due to the Taking-up of Hydrogen in the Course of the Manufacture of Steel. E. Houdremont and H. Schrader. (Iron and Steel Institute, 1941, Translation Series No. 56). An English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, July 10, pp. 671-680.

(See preceding abstract).

The Combined Effect of Hydrogen and Stresses on the Formation of Hair-Line Cracks. E. Houdremont and H. Schrader. (Iron and Steel Institute, 1941, Translation Series, No. 51). An English translation of a report which appeared in Stahl und Eisen, 1941,

vol. 61, July 3, pp. 649-653. (See p. 67 A).

Effect of the Hydrogen Content, Hydrogen Permeability and Hydrogen Solubility on Flake Formation in Steel. H. Bennek and G. Klotzbach. (Iron and Steel Institute, 1941, Translation No. 49). An English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, June 19, pp. 597-606; June 26, pp. 624-630. (See p. 66 A).

The Effect of Cerium on Grey Cast Iron. F. Bischof. (Giesserei, 1941, vol. 28, Jan. 10, pp. 5-9). The author compares the data given in three papers dealing with the effect of cerium on grey cast iron, by Baukloh and Meierling, by Moldenke and by Smalley. He finds the results of the first two papers to be in good agreement, but shows by thermochemical calculation that Moldenke's assumption that the deoxidation with Misch metal is a strongly exothermic reaction is incorrect.

The Properties of Manganese Heat-Treatable Steels Containing Other Alloy Additions. H. Cornelius. (Iron and Steel Institute, 1941, Translation No. 48). An English translation of a paper which was published in Stahl und Eisen, 1940, vol. 60, Nov. 28, pp. 1075–1083. (See Journ. I. and S.I., 1941, No. I., p. 227 A).

Some Properties of Phosphorus-Titanium Steels. G. F. Comstock. (American Society for Metals, Oct., 1941, Preprint No. 4). The author investigated the properties of low-carbon steels containing phosphorus in the range 0.08-0.80%, up to 0.70% of titanium and small amounts of other alloying elements. The object was to determine the composition of a steel, using alloving elements of the lowest cost, which would have a yield point of 50,000 lb. per sq. in, and an Izod impact value above 20 after various forms of heat treatment, including normalising at 900° C. and quenching from 1010° and 1095° C. in water. Additions of copper, chromium, nickel, tin and molybdenum were tried, as well as the substitution of vanadium, zirconium, columbium or aluminium for the titanium in the steel. The composition selected to meet the above requirements was carbon 0.08-0.11%, manganese 0.85-1.25%, silicon 0.15-0.25%, phosphorus 0.10-0.15%, copper 0.45-0.60% and titanium 0.40-0.60%. This steel was also found to be weldable, and tough at -30° C.

Balancing the Composition of Cast 25 per Cent Chromium 12 per Cent Nickel Type Alloys. J. T. Gow and O. E. Harder. (American Society for Metals, Oct., 1941, Preprint No. 21). The authors report on their investigation of the mechanical properties and microstructure of chromium-nickel steels containing chromium 23–27% and nickel 10–13% in the as cast and as aged conditions at room temperature and at elevated temperatures. It was estab-

lished that the factor

Chromium content-16 (Carbon content) Nickel content

should not exceed 1.7 if the alloy is to be substantially austenitic. As this value increases the alloy becomes more ferritic. A ternary diagram is developed to show the phases present in these alloys, and nomographs are presented which show the variations in carbon, chromium and nickel required for wholly austenitic structures. The effect of carbon, nitrogen, and carbon plus nitrogen was studied, and for aged specimens the elongation was found to decrease directly as the value of C + N/2 increased, whilst the yield strength increased directly with increasing value of C + 2N. At elevated temperatures the tensile strength is also a function of C + 2N, but the elongation is a function of C + 2.5N. The optimum nitrogen content suggested by the authors is about 0.08-0.10%. If more than 0.15% is present, the ductility at intermediate temperatures (1400-1600° F.) is lowered and unsoundness in castings may be caused.

Stainless Steel Wire in Aircraft. J. K. Findley. (Wire and Wire Products, 1941, vol. 16, Oct., pp. 581–584). The author discusses the properties of stainless steel wire and its application for aircraft parts such as coil springs, pins, wire rope, cable ends, terminals and control cords. Its low magnetic permeability, high tensile strength and resistance to corrosion in salt-laden atmosphere

render it particularly suitable for these parts.

The Behaviour of Some Cast Crankshaft Materials in Bending and Torsional Fatigue Tests. H. Cornelius. (Giesserei, 1940, vol. 27, Dec. 13, pp. 491–499). The author reports on an investigation of the bending and torsional fatigue strengths of plain, notched and drilled specimens of three malleable cast irons, three grey cast irons alloyed with 1·22–1·37% of nickel and 0·70–1·15% of molybdenum, two high-carbon cast steels (carbon 1·28% and 1·49%), and two rolled steels each containing small amounts of nickel and chromium. The suitability of these materials for making crankshafts is discussed and the results are compared with those obtained in tests on various crankshaft materials previously reported in the literature.

Crankshaft Failures. C. G. Williams and J. S. Brown. (Automobile Engineer, 1941, vol. 31, Nov., pp. 401–405). A report is presented of preliminary experiments carried out in the Research Department of the Institution of Automobile Engineers to ascertain the strength of typical crankshafts under known alternating bending moments. A description is given of the apparatus used. Most of the tests were carried out on oil-engine crankshafts and all the failures occurred across the web and originated at a fillet, usually where the fillet joined the web. The results so far obtained suggest that the factor of safety of oil-engine crankshafts is not sufficient.

Examination of Crankshafts. E. Siebel and G. Stähli. (Giesserei, 1941, vol. 28, Apr. 4, pp. 145-150). The authors developed a new type of machine for the testing of crankshafts, which is illustrated and briefly described in the paper. The position of the crankshaft during the testing in this machine corresponds to that in practice in the engine, and the conditions of stress of the testing machine are compared with those prevailing in practice. During testing the crankshaft is subjected to fatigue stress until the endurance limit is reached. The authors compared the behaviour of cast and forged crankshafts, and found the fatigue strength of the former to be lower than that of the latter. Their running properties, however, were superior. The authors think it possible to improve the strength by modification of design in the area where fractures were observed, especially in cases in which the design of the crankshaft is not determined by the dimensions of the casing. In addition, they state that the strength properties would be improved by the use of a higher quality of cast iron with greater fatigue strength, the higher shear modulus of which would have a very favourable effect on the vibration of the crankshaft at its natural frequency.

Harder Basic Bessemer Structural Steel Killed with Silicon and Aluminium. H. Hauttmann. (Iron and Steel Institute, 1941, Translation Series, No. 60). An English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, Feb. 6, pp. 129–136; Feb. 13, pp. 164–170. (See Journ. I. and S.I., 1941, No. II., p. 28 A).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 70 A-72 A)

Heat Etching as a General Method for Revealing the Austenite Grain Size of Steels. O. O. Miller and M. J. Day. (American Society for Metals, Oct., 1941, Preprint No. 15). The authors studied the factors affecting the grain size of austenite as revealed by heat etching (a technique previously developed by Day and Austin, see Journ. I. and S.I., 1940, No. I., p. 47 a). The size of the austenite grains at the surface of a heat-treated specimen is the same as that of the grains in the interior of the specimen, provided that the metal at the surface has not reacted with the atmosphere in the heat-treatment furnace. If the partial pressure of oxygen in the atmosphere during heat treatment is not low enough, any aluminium or other deoxidising agent present is oxidised at the surface and this oxide retards the growth of the austenite at the surface long after the remainder of the specimen has coarsened. The authors also describe an apparatus for removing all traces of oxygen from the hydrogen used in the heat etching process.

An Improved Cell for Electrolytic Polishing. (Metal Progress, 1941, vol. 40, Sept., pp. 298–299). A brief description is given of a simple and convenient cell for the electrolytic polishing of metal-lurgical specimens. The cell consists of a wooden box 2 in. wide, 3 in. deep and 3½ in. long with a simple tilting mechanism. A hole in the centre of one end is closed by the specimen held in place by a spring clip which also forms the anode contact. The box is lined with paraffin wax and contains sufficient electrolyte to cover the specimen when the cell is in the horizontal operating position. The specimen is put in position and removed with the cell in the tilted position. Current is supplied by a 6-V. battery connected through

a rheostat.

X-Ray Study of the A₃ Point of Pure Iron Using the Geiger-Muller Counter. A. P. Wangsgard. (American Society for Metals, Oct., 1941, Preprint No. 14). The author describes the apparatus and technique for the study of the transformation of pure iron and some results obtained with it. In the method described a Geiger-Müller counter was used to detect the change in the X-ray diffraction pattern as the iron changes from the body-centred to the face-centred phase and back again. The Ac₃ point was found to

occur at $910 \cdot 5^{\circ} \pm 0 \cdot 6^{\circ}$ C. in an atmosphere of pure hydrogen; the Ar₃ point was $2-2 \cdot 5^{\circ}$ C. lower. The body-centred and face-centred crystals could co-exist over a temperature range of about $2 \cdot 5^{\circ}$ C. with some sort of equilibrium between them. It was noted that crystals occasionally disintegrated and reformed rapidly in this temperature range and the author suggests that the atoms have a greater mobility near the Ac₃ and Ar₃ points. The apparatus

used is described in detail in three appendices.

The Acicular Structure in Nickel-Molybdenum Cast Irons. R. A. Flinn, M. Cohen and J. Chipman. (American Society for Metals, Oct., 1941, Preprint No. 2). The authors investigated the isothermal transformation of austenite in nickel-molybdenum cast irons in order to determine the mechanism of the formation of the acicular structures found in these high-strength irons. structures were found to consist of a series of transformation products initiated by ferrite nucleation which form below the temperature range of pearlite. In the upper part of the acicular range very little carbon is precipitated simultaneously with the ferrite, for most of the carbon diffuses into the surrounding austenite as the ferrite grows. Ultimately, however, a dark-etching, ferrite-carbide aggregate emerges out of the austenite, but the latter does not transform completely, being partly retained and partly converted into tetragonal martensite during the cooling to room temperature. In the lower part of the acicular range, the carbon becomes entrapped in the growing ferrite, and precipitates in situ, thus causing a progressive darkening of the ferrite phase. This product also becomes more angular with decreasing transformation temperature and gradually assumes the oriented configuration of the well-known bainite. The increase in strength which occurs on tempering acicular nickel-molybdenum east irons in the 260° to 370° C. range is attributed to the relief of stresses and to transformations occurring within the residual austenite-martensite of the matrix.

Effects of Small Amounts of Alloying Elements on Graphitisation of Pure Hypereutectoid Steels. C. R. Austin and B. S. Norris. (American Society for Metals, Oct., 1941, Preprint No. 28). The authors studied the tendency to graphitisation on tempering steels for prolonged periods at sub-critical temperatures. They examined hypereutectoid 1·1% carbon steels made from electrolytic iron melted and cast under hydrogen and containing about 0·05% of sulphur or tin, or up to about 0·5% of manganese, silicon, nickel, chromium, copper or aluminium. The investigation led to the following conclusions: (1) After quenching to the martensitic state and tempering in the absence of oxygen, only the high-aluminium alloy examined (0·37% of aluminium) showed marked graphitisation, being almost completely graphitised after a 75-hr. anneal within the temperature range 550° to 630° C. (2) For the promotion of carbide dissociation a high dispersion of carbide or the presence of some critical strain seems to be required. Thus the

0.37% aluminium steel failed to graphitise on tempering when the steel was free from strain and its carbide size was comparable to that of commercial spheroidised high-carbon steel. (3) The diffusion of oxygen into the steel during homogenisation or during tempering in an atmosphere of low oxygen pressure may promote graphitisation. This is probably due to a nucleating effect of certain oxides, such as alumina, when present in a suitable form or degree of dispersion. (4) The effectiveness of fine carbide size, strain or oxygen diffusion depends on the presence of certain elements in the steel. Thus the steels containing aluminium, manganese or silicon could be rendered graphitising, whereas those containing nickel, chromium, copper, sulphur (free from manganese) or tin exhibited resistance to graphitisation, independent of strain, carbide size and oxygen penetration. (5) The temperature of maximum graphitisation depends on the nature and amount of alloying element present in the steel. (6) The degree of graphitisation is clearly indicated by the hardness of the alloy after tempering, even if the sub-critical heat treatment is followed by waterquenching. Aluminium, silicon and manganese steels, however, may be almost completely graphitised after treatment at 710° C., although the decrease in hardness is small—a phenomenon which seems to be due to age-hardening.

The Influence of Alloving Elements on the Critical Points of Steels as Measured by the Dilatometer. R. N. Gillmor. (American Society for Metals, Oct., 1941, Preprint No. 13). The author reports the results of an investigation of the effect of alloying elements on the temperature and velocity of the transformation in steel when cooled from 900 to 1000° C. at a rate of 135° C. per hr. The thermal analyses were made by means of an automatic recording Leitz dilatometer. The principal conclusions reached were: (1) More than 1% of manganese, either alone or with other elements such as molybdenum, depresses the Ar₃ point. In plain manganese steels, 3% of this element will depress this critical point by as much as 165° C. (2) Silicon, alone or with other alloying elements, tends to raise the transformation temperature. (3) Tungsten is generally present with other alloving elements and the latter have a greater influence on the transformation than the tungsten. (4) Chromium alone raises the critical temperature, but if the silicon content is normal and more than 1% of either nickel or molybdenum is present the effect of chromium is to depress the Ar, point. (5) In straight molybdenum steels the critical points occur at slightly higher temperatures than in the plain carbon steels, but molybdenum in conjunction with nickel, or with more than 1% of manganese or chromium, markedly depresses the Ar₃ point. (6) Nickel alone depresses the Ar₃ point by as much as 180° C. for 3% of this element. (7) The dilatometer forms a very effective method of measuring the air-hardening characteristics of a steel.

and it is also possible in one test to measure the magnitude of the

phase changes, the velocity at which they take place and their position on the time-temperature curve for any rate of heating and

cooling.

The Effect of Carbon Content and Cooling Rate on the Decomposition of Austenite during Continuous Cooling of Plain Carbon Steels. R. F. Thomson and C. A. Siebert. (American Society for Metals, Oct., 1941, Preprint No. 18). The authors give an account of their investigation of the factors affecting the decomposition of austenite on quenching plain carbon steels. The effects of variations in the carbon content, grain size and cooling rate were studied on specimens subjected to the Jominy end-quench test and curves are presented relating the hardness to the percentage of pearlite

plus ferrite for various carbon contents and grain sizes.

Microstructural Characteristics of High Purity Alloys of Iron and Carbon. T. G. Digges. (American Society for Metals, Oct., 1941, Preprint No. 39). The author studied the microstructural characteristics of high-purity iron-carbon alloys of hypereutectoid composition, and the effect of various impurities on the structure. The alloys were prepared from seventeen irons of various degrees of purity by carburising for 3 hr. at 925° C. in a mixture of hydrogen and benzene vapour. The presence of free ferrite in the hypereutectoid zones proved to be characteristic of the structures of irons of very high purity, free from aluminium and with a total of less than 0.009% of impurities. From this finding the author concludes that if oxygen is responsible for this structural feature, then minute quantities are sufficient and as effective as greater amounts. It could be established that alumina was not responsible for the formation of free ferrite, and that aluminium in excess of about 0.001% inhibited its formation. The presence of hydrogen in the carburising and annealing atmospheres had no detectable effect on the formation of free ferrite. Free ferrite was produced with equal facility in the hypereutectoid zones by cooling directly from the carburising temperature and by annealing in vacuo. It could not be detected in the eutectoid zones of any of the alloys examined, however.

Effects of Initial Structure on Austenite Grain Formation and Coarsening. M. Baeyertz. (American Society for Metals, Oct., 1941, Preprint No. 20). The author investigated the mechanism of the formation of austenite when heating specimens of steel containing 0·45–1·00% of carbon, and found that this differed depending on whether the initial structure was pearlitic or martensitic. In pearlite, nucleation of austenite occurs at the ferrite-cementite lamellar boundaries with the pearlite colonies. Austenite grains do not readily grow across the ferrite grain boundaries which separate the pearlite colonies, so that, in the absence of coarsening, the austenite grain size at the end of the transformation is equal to or less than that of the initial pearlite. In both pearlitic and martensitic structures the formation of austenite begins in the regions which have the lowest Ac₁ point, and these are determined by the

dendritic pattern of the steel. When up to 0.1% of sulphur was added to steels containing carbon 0.15% and 0.60% to which up to 2 lb. of aluminium per ton had been added, the general effect was either to restrict the grain-coarsening or to raise the tempera-

ture at which it took place.

The Velocity of Conversion of Austenite to Ferrite and Cementite. H. A. Schwartz and M. K. Barnett. (Transactions of the American Foundrymen's Association, 1941, vol. 49, Dec., pp. 441-446). The authors report on an investigation of the formation of graphite nodules when cooling cast iron from different temperatures at different rates. Groups of specimens were heated to 900° C., cooled to 825° C, and then cooled at controlled rates of between 100° and 2° C. per hr.; specimens were removed from the furnace at intervals of about 25° C. and quenched in water. They were then examined microscopically to determine the presence or absence of ferrite in the grain boundaries, and the quenching temperature at which graphite nodules appeared. Ferrite was observed in all specimens quenched from above 750° C. It was noted that the rate at which carbon came out of solution was very much greater in the quenching temperature range 750-725° C. than at either above or below this range and that the carbon precipitation rate increased rapidly as the cooling rate was diminished.

Electrical Resistance Method for the Determination of Isothermal Austenite Transformations. F. B. Rote, W. C. Truckenmiller and W. P. Wood. (American Society for Metals, Oct., 1941, Preprint No. 46). The authors describe a method for studying the isothermal transformation of austenite by means of the determination of changes in electrical resistance. The apparatus and test procedure are discussed and the results are compared with those obtained by other methods. The authors' method can be applied in a limited temperature range only. Where applicable, however, it seems to possess certain advantages, the most outstanding one being the relatively short time required for the measurements.

The Transformation of Retained Austenite in High Speed Steel at Subatmospheric Temperatures. M. P. Gordon and M. Cohen. (American Society for Metals, Oct., 1941, Preprint No. 48). The authors studied the behaviour of the retained austenite in hardened 18/4/1 tungsten-chromium-vanadium high-speed steel before, during and after treatment with liquid nitrogen by means of specific-volume, hardness, dilatometric, X-ray diffraction and magnetic measurements. The investigation led to the following conclusions: (1) During the continuous cooling of the steel examined from a hardening temperature of 1285° C. down to -190° C. the austenite transformation sets in at 215° C., progresses through room temperature and stops at about -100° C. (2) Interrupting the cooling at room temperature, as is done in ordinary hardening practice, stops the transformation. (3) Ageing the hardened high-speed steel at room temperature before cooling to -190° C. reduces the magni-

tude of the transformation at sub-atmospheric temperature and lowers the temperature at which transformation begins. stabilising effect on the retained austenite becomes more pronounced the longer the period of room-temperature ageing. (4) The rate of cooling below room temperature and the time of holding below -190° C. have no measurable effect on the extent of the transformation. (5) If the hardened steel is tempered at temperatures between 95° and 470° C. the retained austenite is stabilised sufficiently, so that no transformation occurs during subsequent cooling to -190° C. Tempering at temperatures above 470° C., however, produces enough carbide precipitation from the retained austenite to lower its stability to such an extent that transformation again takes place during cooling to the temperature of liquid nitrogen. (6) Tempering after the low-temperature cooling completes the transformation of the retained austenite, and such tempering shows the same characteristic stages as tempering after ordinary hardening. (7) The additional hardness due to low-temperature cooling is persistent during tempering at temperatures as high as 565° C. (8) The procedure of low-temperature hardening and tempering of 18/4/1 tungsten-chromium-vanadium steel seems to produce combinations of hardness, strength and ductility unattainable by

ordinary hardening and tempering.

The Structure of Pearlite. F. C. Hull and R. F. Mehl. (American Society for Metals, Oct., 1941, Preprint No. 40). The authors discuss the structure of pearlite and the mechanism of its formation, and review the literature on pearlite with particular reference to the theories on its formation. They used Vilella's martensite reagent to develop etch pits in the ferrite component of pearlite in high-purity eutectoid steel. In this manner they could demonstrate that all the ferrite lamellae of a pearlite colony have the same orientation. From this finding, as well as from micrographic evidence presented in the paper, the authors conclude that cementite serves as the active nucleus in the formation of pearlite. They assume that the alternate parallel lamellae of ferrite and cementite in a pearlite colony are produced by a process of lateral nucleation and growth, and are subsequently developed by growth from the edges, the latter mode of growth accounting for by far the greater proportion of pearlite produced. The pearlite spacing established by lateral nucleation and growth decreases as the transformation temperature is lowered, because the rates of nucleation of ferrite and cementite increase more rapidly with supersaturation than do the rates of growth. In conclusion the authors draw attention to a mode of transformation, not previously described, in which pearlite nodules grow many times larger than the austenite grains and form approximately spherical nodules ("group nodules"). This phenomenon was observed in a variety of steels, even in hypoeutectoid ones, if the transformation of austenite to pearlite took place at temperatures near the Ae, point.

The Hardening of Steel. R. F. Mehl. (Campbell Memorial Lecture: Metal Progress, 1941, vol. 40, Nov., pp. 759-765). Structure and Rate of Formation of Pearlite. (Iron Age, 1941, vol. 148, Oct. 30, pp. 45-49). The author considers how the rate of nucleation and the rate of growth affect the formation of austenite on heating and the formation of pearlite on cooling steel. The interaction of the rates of nucleation and growth determines the grain size of the austenite, and the factors affecting these rates are different from those affecting the rate of formation of pearlite. The chemical composition and the interlamellar spacing are the factors affecting the formation of austenite. It is also pointed out that finegrained steels form austenite more slowly than coarse-grained steels even when the interlamellar spacing of the initial pearlite is the same. In the austenite-pearlite transformation at temperatures near Ae₁, the pearlite nucleates preferentially at the austenite grain, but the nodules become very large and form group nodules as explained in another paper (see preceding abstract). At high temperatures the rate of nucleation is small relative to the rate of growth, and a few large nodules form; at low temperatures the rate of nucleation is high relative to the rate of growth and many small nodules appear. In the former case the final nodule is generally much larger than the austenite grain, and in the latter case it is always much smaller. A photomicrograph of pearlite at 25,000 diameters is reproduced and this shows that cementite occasionally seems to bridge the lamellæ. The author points out that an examination of 200 photomicrographs reveals that there are no areas in a sample composed of what is frequently called nodular troostite that cannot be resolved into lamellar pearlite.

The Interlamellar Spacing of Pearlite. G. E. Pellissier, M. F. Hawkes, W. A. Johnson and R. F. Mehl. (American Society for Metals, Oct., 1941, Preprint No. 41). The authors critically review the methods used so far for the determination of the interlamellar spacing in pearlite, and suggest a new mathematical-analytical method which furnishes improved data. This method permits the demonstration of the interlamellar spacing in (isothermally-formed) pearlite by a distribution curve with values statistically distributed about a mean value which serves to specify the spacing. The data presented indicate that the interlamellar spacing does not vary with either the austenitic grain size or the austenising temperature. An increase in carbon content above the eutectoid composition resulted in a decrease in the lamellar spacing. The same effect was brought about by cobalt, whereas manganese and nickel had little direct influence on the spacing. Further, the authors found that the interlamellar spacing varied approximately exponentially with the temperature of formation.

A Study of Martensite Transformation by a Photometric Method. E. R. Saunders and J. F. Kahles. (American Society for Metals, Oct., 1941, Preprint No. 43). The authors developed a photometric

method for the measurement of the amount of martensite formed during the transformation. The method is based on the assumption that the percentage of austenite transformed is indicated by the percentage of the dark constituent developed in the steel specimen. A photograph of the apparatus used is produced in the paper and the technique employed is described in detail. Steel samples were quenched from the austenitic state to a given temperature below the Ar" point and held there for a measured time interval; they were then tempered at a temperature above the Ar" point and subsequently quenched at room temperature. The martensite formed during the first quench, together with that formed during the holding below Ar", appears as a dark acicular structure against a white background. At the end of the sub-Ar" treatment the white matrix represents the undecomposed austenite, whereas after the final quench it consists of martensite and possibly some rotained austenite. The results, which are in agreement with those of Greninger and Troiano (see Journ. I. and S.I., 1940, No. II., p. 198 A), indicate that the so-called S-curve theory does not hold good for eutectoid plain carbon steel.

The Martensite Thermal Arrest in Iron-Carbon Alloys and Plain Carbon Steels. A. B. Greninger. (American Society for Metals, Oct., 1941, Preprint No. 42). The author developed a gas-quenching apparatus for high-velocity thermal analysis. Helium gas was used as the quenching medium, and time-temperature curves were recorded with the aid of a short-period torsion galvanometer and a drum camera. The author determined the temperatures of the martensite thermal arrest as a function of the carbon content in both high-purity iron-carbon alloys and plain carbon steels. Cooling rates of up to 4000° C. per sec. were used. Time-temperature curves were also recorded during the quenching of small steel specimens in liquid-metal baths. The results of the investigation indicate that the martensite transformation in steel cannot be suppressed by increasing the rate of cooling, i.e., the rate of cooling

has no effect upon the Ar" temperature.

The Carbon-Oxygen Equilibrium in Liquid Iron. S. Marshall and J. Chipman. (American Society for Metals, Oct., 1941, Preprint No. 53). The authors studied the equilibrium between carbon and oxygen in liquid iron and carbon monoxide and dioxide in the gas phase in the range 1540° to 1700° C. The investigation was carried out at pressures up to 20 atm., and the authors therefore designed a special high-pressure furnace, a sketch of which is reproduced in the paper. They determined equilibrium constants for the following reactions:

 $\begin{array}{l} {\rm C_{(in\;Fe)}\,+\,CO_{2(gas)}} = 2{\rm CO_{(gas)}} \\ {\rm O_{(in\;Fe)}\,+\,CO_{(gas)}} = {\rm CO_{2(gas)}} \\ {\rm C_{(in\;Fe)}\,+\,O_{(in\;Fe)}} = {\rm CO_{(gas)}} \end{array}$

Taking the activity coefficients of carbon and oxygen into account,

the values of the constants at 1540° C. were found to be respectively 430, 1.21 and 512. The effect of temperature upon the constants (designated as K_1 , K_2 and K_3 is given by the following equations:

$$\log K_{1^{'}} = -5778/T + 5 \cdot 784 \\ \log K_{8^{'}} = 7200/T - 3 \cdot 855 - 9 \times 10^{-6} \, (T - 1873)^{2} \\ \log K_{8^{'}} = 1860/T + 1 \cdot 643$$

CORROSION OF IRON AND STEEL

(Continued from pp. 72 A-73 A)

A Practical and Theoretical Explanation of Corrosion. W. G. Imhoff. (Products Finishing, 1941, July, pp. 56-69; Aug., pp. 50-60). The author attempts to answer the questions: What is rust? What are the agents of corrosion? What is corrosion? He discusses two theories of the cause of corrosion, namely, the chemical theory supported by Cushman, Gardner and others, and the electrolytic theory formulated by Whitney in 1903. He then discusses ionisation and develops the following theory: All acids when dissolved in water furnish hydrogen ions. The properties of acids are based on the formation of these ions, and this, linked with the fact that all acids dissociate with the formation of hydrogen ions, means that there is really only one acid, namely, the hydrogen ion. As it is impossible for the chemical theory to operate other than by the mechanism of ionisation, which is also the mechanism by which the electrolytic theory operates, the two theories are really one. Finally, oxidation is the mechanism by which the products of ionisation may be removed in order that the process of corrosion may be continuous, so that to stop continuous corrosion it is necessary to prevent both ionisation and oxidation.

Cathodic Protection as a Possible Means for Preventing Corrosion of Gas Well Casing. W. E. Huddleston. (Proceedings of the Natural Gas Section of the American Gas Association, 1941 Annual Meeting, pp. 207-212). The author explains the principles of cathodic protection (see Journ. I. and S.I., 1940, No. II., p. 231 A) and describes the equipment used for applying this technique to the prevention of the corrosion of gas well casing. Some results obtained by tests to a depth of 1000 ft. on a 6½-in.-dia, casing are

presented and discussed.

Fretting Corrosion and Fatigue Strength: Brief Results of Preliminary Experiments. E. J. Warlow-Davies. (Proceedings of the Institution of Mechanical Engineers, 1941, vol. 146, pp. 32-38). Fretting corrosion, the conditions under which it occurs, and the possibility of its effect on fatigue strength, are discussed. Fretting corrosion always appears in regions of unknown stress concentration, so that an accurate estimate of the weakening effect due to it cannot be made from combined fretting and fatigue tests. It is suggested that fatigue tests of previously fretted test pieces, analogous to determinations of the percentage loss of fatigue strength by prior stressless chemical corrosion, would be useful. Apparatus for making such tests is described, and preliminary results for a medium-carbon steel and for a nickel-chromium-molybdenum alloy steel are given. The losses of fatigue strength after fairly severe fretting were 13% and 18% respectively. Although these are not necessarily maximum values, reductions of this order are regarded as justifying further investigation, and the suitability of the apparatus and methods used is considered.

The Exploration and Combating of the Intercrystalline Corrosion of Unalloyed Steels. H. Houdremont, W. Bennek and H. Wentrup. (Iron and Steel Institute, 1941, Translation Series, No. 44). An English translation of a paper which appeared in Stahl und Eisen, 1940, vol. 60, Aug. 29, pp. 757–763; Sept. 5, pp. 791–797. (See

Journ. I. and S.I., 1941, No. II., p. 101 A).

The Influence of Stress on the Corrosion Pitting of Steel in Distilled Water. D. J. McAdam jun. and G. W. Geil. (American Society for Metals, Oct., 1941, Preprint No. 25). The authors report on their investigation of the effect of stress applied during corrosion on the shape, size and distribution of the corrosion pits in specimens of a 3.7% -nickel steel. It was observed that pits formed in distilled water were smaller and shallower than those formed in well water. The application of stress cycles tended to increase the size and depth of the corrosion pits. A constant stress, if sufficiently high, accelerated the formation of pits in specimens in distilled water but not in well water. At sufficiently high stress and frequency, crevices or fissures extending radially from the pits were formed. The fatigue limit of the steel was reduced more slowly by corrosion in distilled water than by corrosion in well water, the difference being due to the difference in size and depth of the pits. Curves are presented showing the decrease in the fatigue limit caused by applying stresses during the period o corrosion.

Test for Corrosion of Painted Iron. R. B. Gibney. (Bell Laboratories Record, 1941, vol. 20, Oct., pp. 35–37). The author describes an apparatus for making short-time tests to determine the protective value of different paint pigments. The apparatus consists of glass tubes filled with water connecting the paint film to a calomel reference electrode. The end of the tube rests on the spot to be measured and is surrounded with an enveloping tube through which nitrogen is passed. A recording potentiometer connects the calomel electrode to the back of the painted panel through an amplifier. The potential of a corroding metal becomes more electro-negative with time, whilst that of a non-corroding metal becomes or remains electro-positive. In these tests the time required for the potential to reach its lowest value indicates the protective value of the coating—the longer the time the better the

rating. Agreement between the ratings obtained by the potentiometric test and by a one-year atmospheric exposure test was obtained in 18 out of 22 cases.

BOOK NOTICES

CHALMERS, B., and A. G. QUARRELL. "The Physical Examination of Metals." Vol. II. "Electrical Methods." 8vo. pp. viii+ 280. London (1941): Edward Arnold & Co. (Price 20s.)

This is the second of two volumes dealing with the physical examination of metals. The first volume, which was devoted to optical methods, was excellent in every way, but this second volume is most disappointing. It is indeed difficult to appreciate that the first three chapters have been written as recently as 1941, as most of the material in them would not have been up to date twenty years ago. The first chapter consists of less than two pages, and serves as a general introduction to the book. It is particularly disappointing to find a serious inaccuracy in the first paragraph, where it is stated that in a permanent magnet, magnetism is caused by movements of the electrons in the atoms of which they form a part, whilst in an electromagnet it is due to the flow of electrons along a wire.

The second chapter is devoted to magnetism in general, and covers magnetic properties and materials, measurement of magnetic properties and descriptions of methods of detecting flaws by virtue of

magnetic phenomena.

The treatment of the subject is based on the magnetic-pole hypothesis, and nowhere is reference made to the magnetic-circuit hypothesis, which was generally accepted many years ago. The section devoted to measurement of magnetic properties leaves much to be desired. The properties of modern magnetic materials are now seldom, if ever, determined by the magnetometer method. The modern and generally used method of testing permanent magnets forms the subjectmatter of a British Engineering Standards Specification, but no reference is made to this. The most modern part of this chapter is the section devoted to the use of the cathode-ray oscillograph for the determination of magnetic properties, but unfortunately the information given is somewhat misleading. The most interesting and useful sections of this second chapter are probably those dealing with magnetic tests for irregularities and discontinuities.

It is difficult to realise why, in Chapter 3, the authors have included sections dealing with the measurements of electrical resistance and with thermo-electricity. Both are adequately dealt with in text-books and are covered by university courses. The section dealing with the measurement of capacity is interesting in view of the extended use that is now being made of the principles that the authors shortly but

adequately describe.

Chapters 4 and 5 are the best two chapters in the book. Chapter 4 gives a brief but very understandable review of various aspects of X-ray diffraction. Inter alia, it deals with space lattice, the production of X-rays, X-ray diffraction methods, &c., and concludes with an interesting section devoted to the metallurgical application of X-ray diffraction methods.

One of the authors, Dr. Quarrell, is well known for his work on the diffraction of electrons, and it is hence not surprising to find that Chapter 5 is a masterly review of that subject. Chapter 6, dealing

with the electron microscope, is also adequate.

Chapter 7 deals with radiography, and one can find fault with it

only because of its shortness.

The authors will doubtless be glad to hear that Kodak Maximum Resolution plates are at least as grain-free as the Lippmann emulsion supplied in pre-war days by Messrs. Gevaert and are suitable for micro-radiography.

J. FERDINAND KAYSER.

Greenwood, J. Neill. "Glossary of Metallographic Terms." 8vo. pp. 82. Melbourne and Sydney, 1940; Tait Publishing Co. Pty., Ltd. (Price 5s.)

This publication is intended primarily for students of metallography and others who need to know something of this subject but have neither the time nor the opportunity for a full study of it. In compiling this glossary, the author has attempted to give something more than a definition in most cases. Further, at the end of each section cross-references are given to other sections which have a bearing on the particular subject. It makes no pretence to be exhaustive so far as the number of terms is concerned. It is thought, however, that even on controversial matters, the attempt to combine varied points of view has given a meaning to a word or phrase which will be workable, so that whilst experts may quibble, the bulk of those for whom it has been written will benefit by a selection having been made.

HUME-ROTHERY, W. "Researches on the Structure of Alloys." (Research Reports of the British Non-Ferrous Metals Research Association, Association Series No. 562). 8vo. pp. 20. London 1941: The Association. (Price 2s. 6d.)

During more than fifteen years Dr. W. Hume-Rothery has been responsible for a remarkable series of researches on metallic alloys carried out in the laboratories of the University of Oxford. This work has been directed mainly to the establishment of the general principles which decide: (1) whether, and in what proportion, two or more metals are capable of forming solid solutions, (2) the structural and equilibrium characteristics of alloy systems, and (3) the properties of alloys. These are, in fact, the general principles of physical metallurgy. In the course of the large amount of delicate and accurate experimental work involved, new and improved techniques of various kinds have been developed. The investigations so far completed have been published in more than thirty papers in the Proceedings of the Royal Society, the Journal of the Institute of Metals and elsewhere. The practical importance of the work, apart from its great scientific interest, lies in its promise of providing means for forecasting the properties of alloys from the atomic characteristics of the constituent metals, and thus permitting the building up of alloys of desired properties. For some years past the British Non-Ferrous Metals Research Association has made a contribution towards the cost of these investigations, and Dr. Hume-Rothery has now written a concise account of the work done since this support began. In this clear review of 20 pages' length Dr. Hume-Rothery has been more concerned to set out the plan, aims and main conclusions of his work than to give the detailed results which are published elsewhere. Nevertheless he has found it possible to indicate broadly the experimental results obtained and the evidence on which his conclusions rest. A list of the published papers mentioned is appended to the report. 1942 - iK

LARKIN, E. J. "Works Organization and Management." Foreword by Dr. W. Alfred Richardson. La. 8vo. pp. xxiii + 465. Illustrated. London 1941: New Era Publishing Co., Ltd. (Price 35s.)

The author of this volume is Lecturer in Factory Management and Machine Design at the Derby Technical College and Repton School. In dealing with works organisation and management he has taken a very broad view, and has included chapters on the selection of a foundry site and the layout of factories which to many authorities on this important subject would be deemed unnecessary in a work of this description. The book is well illustrated with 360 diagrams, tables and photographs, and includes an appendix of useful information for reference purposes. It should prove a helpful work to the advanced student, and of considerable use in the solution of problems met with in the organisation and running of factories. The thirty chapters deal with the following: The Management Function; Selection of a Factory Site; Layout of Factories; Power Supplies; Heating and Ventilation; Industrial Lighting; Machine Tools; The Tool Room; Jigs and Fixtures; Personnel; Industrial Accidents—and Their Prevention; The Larkin System of Workshop Training; The Embryo Engineer, Time Recording; Workshop Expenses; Elimination of Waste; Shop Transport; Motion and Time Study; Payment by Results; Drawing, Design, and Initiation of Manufacture; Estimating; Production Planning; Progressing and Scheduling; Industrial Standardization; Research and Technical Development; Purchasing; Ordering Specifications; Inspection Standards; Storekeeping; Sales Organization and Tendering.

ORES-MINING AND TREATMENT

(Continued from pp. 42 A-43 A)

Developments in the Concentrating of Minnesota Iron Ores. T. B. Counselman. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1395: Metals Technology, 1941, vol. 6, Nov.). The author describes various improvements in the methods of concentrating the lower-grade iron ores of the Mesabi Range. These improvements may be summarised in chronological order as follows: (1) Magnetising roasting and concentration; (2) the development of improved jigs and improved jigging practice; (3) separation in a medium of crushed ferro-silicon in water having a specific gravity of about 3.20; (4) the application of jigging to hard ores; and (5) simplified plants for small tonnages.

The New Ore-Mixing Plant of the Buderus'sche Eisenwerke at the Sophienhütte in Wetzlar. H. Oberle. (Iron and Steel Institute. 1941, Translation Series, No. 54). An English translation of an article published in Stahl und Eisen, 1941, vol. 61, May 29, pp. 529–535. (See Journ. I. and S.I., 1941, No. II., p. 106 A).

REFRACTORY MATERIALS

(Continued from pp. 43 A-44 A)

Reactions in Mixtures of Chromite, Magnesia and Alumina, Part I. The Influence of Boric Acid and of Calcium Fluoride in Promoting Combination. W. Hugill, A. Watts and J. Vyse. (Transactions of the British Ceramic Society, 1941, vol. 40, Oct., pp. 363-379). It is known that chrome-magnesite bricks have a marked tendency to absorb iron oxide during service and that disintegration of the brick is mainly due to growth of the chromite grains by this intake of magnetite. Magnesia, in common with chromite and magnetite, crystallises in the cubic system, but differs from them both in lattice dimensions and in atomic arrangement; alumina in the form of corundum differs from all three in that it crystallises in the hexagonal system. The authors have therefore investigated the possibility of combining chromite with varying proportions of magnesia and with alumina, in the hope that, by altering lattice dimensions, the intake of magnetite would at least be limited. Part I. of this investigation is in two sections. In Section I. three series of briquettes were made from mixtures of synthetic chromite (FeCr₂O₄), calcined alumina and light magnesium oxide, (a) without the addition of mineralisers, (b) with boric acid, and (c) with the addition of synthetic fluorite. In Section II. briquettes made of chrome ore, commercial dead-burned magnesite and pure alumina were examined. The general conclusions were: (1) Measurements of changes of colour and density and examination under the microscope of mixtures of synthetic chromite with pure magnesia and alumina indicated that chrome spinel can take a considerable amount of alumina into solid solution, up to at least 30%. (2) The influence of the two mineralisers used depended on the composition of the batches. (3) Comparing batches made from commercial materials with corresponding compositions in the synthetic series, it was noticeable that boric acid exerted a greater influence over a wider range of compositions. (4) Free magnesia occurred over a wider range in composition in the commercial series than in batches made from pure materials. It is probable that the reduced proportion of actual chromite present in the former as compared with the latter series, limits the amount of magnesia which can be taken up. (5) With regard to the effect of alumina on the lattice dimensions of chromite, the microscope revealed that batches with 30% addition of alumina became homogeneous on firing. The product had the properties of a spinel. (6) The low rate of diffusion of magnesioferrite and spinel at 1600° C. was confirmed; the presence of excess magnesia appeared to retard the rate of diffusion.

Reactions in Mixtures of Chromite, Magnesia and Alumina. Part II. The Proportion of Extractible Magnesia in the Fired Mixes. W. Hugill and J. Vyse. (Transactions of the British Ceramic Society, 1941, vol. 40, Oct., pp. 380-387). The fired pure chromitemagnesia-alumina mixes and the fired commercial chrome-ore/ magnesite/alumina mixes prepared for Part I. of this investigation (see preceding abstract) were subjected to extraction by ammoniacal ammonium-chloride solution for the purpose of determining the uncombined magnesia. This reagent dissolves periclase, but has negligible action on magnesium silicates and spinels. The results confirmed the occurrence of the reactions:

 $\begin{array}{l} \text{(1a) } \operatorname{FeCr_2O_4} + \operatorname{MgO} = \operatorname{MgCr_2O_4} + \operatorname{FeO} \\ \text{(1b) } \operatorname{4FeO} + 2\operatorname{MgO} + \operatorname{O_2} = 2\operatorname{MgFe_2O_4} \\ \text{(2) } \operatorname{Al_2O_3} + \operatorname{MgO} = \operatorname{MgAl_2O_4}, \end{array}$

in the mixes prepared from the pure materials, and of the further reaction:

(3)
$$SiO_2 + 2MgO = Mg_2SiO_4$$

in the commercial materials containing siliceous impurities.

Casting Pit Refractories. J. H. Chesters. (Iron Age, 1941, vol. 148, Nov. 20, pp. 43-49; Nov. 27, pp. 53-58). The author discusses types of refractories for ladles, launders, ingot tops, ladle stoppers, stopper parts, and runners for bottom-poured ingots. Encouraging results have been obtained with plumbago bricks in ladle linings. These bricks are made by firing a mixture of 70% of medium alumina clay with 30% of high-grade flake graphite; these

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bricks have worn back at a negligible rate compared with that of the surrounding fireclay brickwork. It is suggested that improvements in ladle lining life will be obtained by the use of denser fireclay brick of high alumina content, the use of plumbago bricks with a more suitable cement, and with monolithic linings made from either "basic" (burned dolomite) or stabilised dolomite clinker rammed in place with a suitable bond.

An Inexpensive Stopper Rod Drying Oven. H. T. Klein. (Steel, 1941, vol. 109, Dec. 1, pp. 93–94). A brief illustrated description is given of a drying oven for ladle stopper-rod assemblies. This furnace has been devised to improve the quality of stopper rods by ensuring good joints between the sleeves and between the bottom sleeve and the stopper. The oven is heated by placing in it a thimble of slag

taken from the ladle after pouring the last ingot.

FUEL

(Continued from pp. 83 A-84 A)

Determining Unsteady-State Heat Transfer in Solids. V. Paschkis and H. D. Baker. (American Society of Mechanical Engineers: Heat Treating and Forging, 1941, vol. 27, Aug., pp. 375-378; Oct., pp. 504-506). When a solid mass is changing temperature there are variable temperature gradients in the mass, a series of isothermal surfaces, a non-uniform changing temperature field within it and a period of time before a steady rate of heat transfer to the surroundings is achieved. These are the factors which influence the unsteady state of heat transfer. Electrical models as a means of solving heattransfer problems have long been known. Such models have been based on a geometrical similarity between the body subjected to heat-flow and the model body. In the present paper the authors describe a new electrical method in which the model has no geometrical similarity to the body being investigated; instead it is based on identity in form of the fundamental equations, and with this type of model a single electrical installation can be immediately adapted to a wide range of heat-transfer problems; the solutions are then rapidly obtained by direct manipulation of instruments. The theory of the method is explained and an example of its application to an unsteady-state of heat-transfer problem is given, with a description of the apparatus used.

An Unusual Washery Problem. J. G. Bond. (Iron and Coal Trades Review, 1941, vol. 143, Dec. 26, pp. 597–598). The author explains how the difficulty of separating washed smalls from slurry at a coal washery was met by the installation of a flocculation plant. This plant is described in detail and particulars of the yield and

operating costs are given.

Pretreatment of Coals for Low Temperature Carbonisation. (Coke and Smokeless-Fuel Age, 1941, vol. 3, Dec., pp. 276-279). Some results of investigations of the swelling properties of German coals carried out by the Vereinigung für Steinkohlenschwelung (Association for the Low-Temperature Carbonisation of Coal) are presented and discussed. The data were obtained with an apparatus in which the pressure developed by the coal when heated in a stream of nitrogen was measured. Several pressure-temperature curves are shown, and these demonstrate how thermal pretreatment of the coal for 2 or 3 hr. at about 380° C. considerably reduces the pressure peak.

PRODUCTION OF IRON

(Continued from p. 84 A)

Why Dry Blast Equipment is Different Now. L. L. Lewis and R. V. Dunne. (Blast Furnace and Steel Plant, 1941, vol. 29, Oct., The authors review the development in the United pp. 1119–1125). States of refrigeration plant for removing moisture from air, with special reference to the introduction of centrifugal compressors. Its application for drying blast-furnace blast is also dealt with.

Air Conditioning Benefits Blast Furnace Operation. E. K. Miller. (Steel, 1941, vol. 109, Nov. 10, pp. 88-94, 112, 113). The author describes the benefits which have resulted from the installation of a blast-conditioning plant at a blast-furnace producing about 1200 tons of iron per day in the Pittsburgh district. The moisture in the air is reduced by refrigeration from an average of 5.5 grains per cu. ft. to about 3.3 grains per cu. ft., and data for the four months June to September, 1941, reveal that the iron production was increased by about 16% and the coke consumption reduced by 4.26%. It is expected that the average increase in production over twelve months will be not less than 8%.

Experimental Manufacture of Nickel-Chromium Pig from New Caledonian Iron Ore. T. Fujiwara and N. Nemori. (Tetsu to Hagane, 1941, vol. 27, June, pp. 363-368). (In Japanese). The authors report on experiments in the production of nickel- and chromium-bearing pig-iron from New Caledonian ore containing 0.2-0.3% of nickel and 2.5-3.0% of chromium. When this ore was used as part of a blast-furnace charge the greater part of these elements was lost, but electric-furnace smelting of this ore alone was much more successful.

Reducing Iron Ore with Hydrogen. M. H. Kalina. (Iron Age, 1941, vol. 148, Dec. 11, pp. 39-43). The author describes an investigation of the manner in which the reduction of lumps of iron ore progresses from the outside to the interior. Hydrogen was used as a reducing agent, and three varieties of ore with porosities ranging from 7.4% to 60% were tested, the degree of reduction throughout the specimen being found by analysing samples taken at different depths. Cylindrical specimens $2\frac{1}{2}$ in. $\log \times 1$ in. in dia. were prepared and the samples were taken from sections in the middle of the cylinder; these were analysed for free iron, ferrous iron and ferric iron. In the ore with a porosity of 60%, reduction took place throughout the specimen. On the basis of the percentage of oxygen removed, the rate of reduction in the centre was half that on the surface. Samples with 37% porosity were less thoroughly reduced at the centre, and in the case of a dense Alabama ore the reaction was confined chiefly to a narrow zone 0.04 in. wide. The author discusses the application of the results to the reduction of high-grade ores for producing very pure iron for powder-metallurgy purposes

ores for producing very pure iron for powder-metallurgy purposes.

Relations between the Chemical Composition and the Viscosity of Metallurgical Slags, and the Technical Importance of these Relations. H. Hellbrügge and K. Endell. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Jan., pp. 307-315). The authors point out that the older conception of the occurrence of stoichiometric compounds in silicate melts has been replaced by the assumption of far-reaching electrolytic dissociation in the melt. On the basis of their own experiments and data from the literature they enumerate the following factors as affecting the viscosity of silicate melts: The number of cations built into the silica lattice, the ion radii and the valencies of the cations, the valency of cations in the anion complex, the number of voids in the SiO₄-tetrahedron structure and the oxygen/silicon Preliminary experiments indicated that the anions also have some effect on the viscosity. The substitution of metal oxides by equivalent quantities of fluorides or chlorides resulted in considerable decrease in the viscosity. By the examination of experimental melts the lime in which was replaced by magnesia, and by the evaluation of data obtained by McCaffery for the viscosity in the system MgO-CaO-Al₂O₃-SiO₂ (see Journ. I. and S.I., 1931, No. I., p. 591) the authors proved that Endell and Brinkmann's formula (see Journ. I. and S.I., 1940, No. I., p. 127 A), which enables a conclusion regarding the viscosity to be drawn from the composition, is applicable to all blast-furnace slags of normal composition, provided that the characteristic viscosity number (Zähigkeitskennzahl) is within the range 0.5-2. (The characteristic viscosity number, a criterion introduced by Endell and Brinkmann (loc. cit.), is the ratio of the sum (in weight-%) of the oxides, fluorides and sulphides decreasing the viscosity coefficient at 1400° C. to the sum (also in weight-%) of the oxides increasing this value). The authors suggest a simplified equation which allows of the approximate calculation of the viscosity at 1400° C. direct from the sum (in weight-%) of $SiO_2 + Al_2O_3$. The authors' attempt to apply Brinkmann and Endell's equation also to open-hearth slags proved a failure, which they think to be due to the fact that these slags do not consist of a silicate structure. In conclusion, they briefly explain the effect of

the electrolytic dissociation of silicate melts on the course of various metallurgical reactions such as deoxidation, dephosphorisation and

desulphurisation.

The Manufacture of Articles from Powdered Metals. W. D. Jones. (Manchester Association of Engineers: Engineering, 1941, vol. 152, Dec. 26, pp. 515–516). The author reviews progress made in the manufacture of articles by the powder-metallurgy technique and describes in detail how porous bronze bearings and iron gear wheels for automobile oil pumps are made.

FOUNDRY PRACTICE

(Continued from pp. 84 A-90 A)

Is the Melting Furnace a Decisive Factor for the Quality of Cast Iron? E. Piwowarsky. (Giesserei, 1941, vol. 28, May 2, pp. 193-197). The author collected data on the strength of cast iron produced under different conditions in a variety of furnaces, and reproduces a diagram, based on about 2000 separate values, in which the tensile strength is plotted against the $(C + \frac{1}{3}Si)$ percentage. He comes to the following conclusions: (1) Independent of the melting furnace, all cast irons of the composition range $(C + \frac{1}{3}Si = 2.8 - 3.6\%)$ are liable to low strength values, unless special means—particularly suitable ladle additions—are applied which result in a disordered graphite formation; (2) the low strength values are very marked only for wall thicknesses up to about 30 mm; (3) the strength values and the reliability of the analysis of cast irons with 2.4-2.8% of carbon might be further improved, again independent of the melting furnace used; and (4) in the concentration range of 2.8-3.6% of $(C + \frac{1}{3}Si)$ the cupola practice might be considerably improved.

Automatic Malleablizing Cycle Control. R. Trautschold. (Steel, 1941, vol. 109, Nov. 24, pp. 89, 95). The author gives a brief and illustrated account of the temperature measuring and controlling devices installed on ten gas-fired furnaces for malleablising cast iron. A cam-operated automatic form of control is used, the contour of

the cam being cut to produce the desired temperature cycle.

Cast Steel Mortar Shells. E. Bremer. (Foundry, 1941, vol. 69, Nov., pp. 51–55, 124, 126). The author describes the foundry equipment and processes for casting and heat-treating steel trenchmortar bodies at an American foundry where a high degree of

mechanisation has been introduced.

Plaster Patterns for Foundry Use. H. Plucknett. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 66, Jan. 15, pp. 35–36, 39). The author describes methods of preparing plaster and the making of plaster patterns and moulds for connecting-rods, cylinders, brake-drums, gutters and pressing-tools.

Core Mixtures Controlled by Hot Strength Test. F. B. Riggan. (Foundry, 1941, vol. 69, Nov., pp. 61, 151–153). The author discusses changes which a foundry made in the composition of core mixtures in order to obtain greater strength when used under certain difficult conditions. It had been found that large oil-sand cores took a very long time to bake through to the centre. The compositions of three standard core mixtures which were developed for three types of castings are given. Their strength at 2500° F. was measured, and it was found that adding up to 2% of iron oxide increased the hot strength considerably.

Moulding Problems in the Electric Steel Foundry. E. J. Kelly. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 66, Jan. 1, pp. 3–5). The author describes and illustrates some methods of preparing moulds in a jobbing steel foundry using green

sand and dry sand moulds.

Tin Forms Used in Molding Operations. W. A. Smith. (American Foundryman, 1941, vol. 3, Nov., pp. 10–13). The author describes the application of tin forms in moulding operations. Tin forms are shaped pieces of tinplate attached to patterns in such a manner that when the pattern is withdrawn the tinplate remains in the mould. They are used for several purposes, e.g., when the pattern, if made solid, could not be withdrawn from the mould, as in the case of a catch for a furnace door; they are also used to form screw-threads and to obtain greater accuracy, smoothness of surface, or finer detail than can be obtained from sand at important parts of a casting. A number of examples are described and illustrated.

The Production of Machine-Tool Castings. (Machinery, 1942, vol. 59, Jan. 1, pp. 381–387; Jan. 8, pp. 421–425). An illustrated description is given of the various departments at the recently reorganised works of Modern Foundries, Ltd., where both ferrous and non-ferrous castings for the machine-tool industry are made. The departments include a modern laboratory equipped with polishing machine, microscope and photographic apparatus and

a darkroom.

PRODUCTION OF STEEL

(Continued from pp. 90 A-92 A)

Some Features of Steel Plant Power Transmission Protection. F. O. Schnure. (Iron and Steel Engineer, 1941, vol. 18, Nov., pp. 30–32). The author describes the measures adopted by the Bethlehem Steel Co. to protect electric power transmission lines from lightning and to reduce plant stoppages caused by short circuits.

Design, Construction and Operation of Open Hearth with Basic Roof. L. B. Lindemuth. (Iron Age, 1941, vol. 148, Nov. 6, pp. 47-54; Nov. 13, pp. 44-49). The author gives details of the design

and operation of two 150-ton open-hearth furnaces at the works of Richard Thomas and Co., Ltd., in South Wales, and one 125-ton furnace at the works of Broken Hill Proprietary Co., in New South Wales, all three of which are examples of the successful application

of basic bricks for roof construction.

Some Notes on Arc-Furnace Melting. N. F. Dufty. (Metal Treatment, 1941, vol. 7, Winter Issue, pp. 138-140, 142). The author discusses electric-furnace maintenance and melting practice for a Héroult-type arc furnace using three-phase 50-cycle A.C. and melting with full or partial oxidation. He suggests the following specification for a 30-ton furnace: Diameter at foreplate, 16 ft.; foreplate to roof, 5 ft.; side walls, 10° slope to vertical; roof, 14 in. of silica brick; sidewalls, 18 in. of metal-cased magnesite backed by 3 in. of insulating brick; bottom, 12-in. rammed graded dolomite, 9-in. stabilised dolomite brick, 41-in. magnesite brick, and 41-in. of insulation; electrodes of graphite 18 in. in dia. with 40-in. centres; hearth to rotate 60° each side of the centre line; bath run-out for basket charging. Such a furnace should give a tap-to-tap cycle of $4\frac{1}{2}$ hr., a melting time of $1\frac{1}{2}$ hr. and an output of about 1000 tons of alloy steel in a 7-day week.

Electrically Melted Steels and the Engineer. N. F. Dufty. (British Steelmaker, 1942, vol. 8, Jan., pp. 10-11). The author discusses the advantages and disadvantages of using electric-arc and high-frequency furnaces for making steel, in considering how the high cost of electric-furnace steel might be reduced, suggesting that both arc and high-frequency furnaces could be installed in the same shop as Bessemer converters or large tilting open-hearth furnaces refining molten pig iron. Hot metal would be available for the arc furnace at frequent intervals, and the high-frequency furnaces would normally melt cold scrap, but hot metal would be available if required. Under this scheme the whole production of basic openhearth or Bessemer steel for girders, plates and rails, and cheap electric steel for highly stressed parts and special applications from ore to finished product would be under the control of one company and its staff of metallurgists, and would also reap the benefits of a

co-ordinated sales organisation.

Welded Ladles for Open-Hearth Service. F. L. Lindemuth. (Steel, 1941, vol. 109, Nov. 24, pp. 74-77). The author presents data on the design of round and elliptical welded steel ladles with capacities of 50-175 tons of molten steel. It is pointed out that with welded construction the weight of the ladle is about one-sixth that of the contents, whereas for riveted ladles the weight ratio is 1:4.

Steel Plant Cars, Their Design, Application and Features. G. P. Astrom. (Steel, 1941, vol. 109, Dec. 8, pp. 82-88). The author traces the development of cars for slag, mixer metal and ingot moulds in the United States, and describes and illustrates some cars of

recent design.

FORGING, STAMPING AND DRAWING

(Continued from pp. 92 A-93 A)

Forging of Shell. W. Naujoks. (Metal Progress, 1941, vol. 40, Oct., pp. 543–554). The author describes and illustrates the machines, furnaces and processes now used in the United States for making shell forgings. The important feature of the upsetting and piercing machines described is that they produce shells of such uniform dimensions that no machining of the cavity is required.

Modern Shell Forging and Torpedo-Body Production. A. B. Cudebee and E. Loewy. (Mechanical Engineering, 1941, vol. 63, Nov., pp. 783–786). The authors describe the Baldwin-Omes, the Loewy hydraulic and the Witter piercing processes of producing shell forgings. They also give particulars of a horizontal-tube draw-bench 154 ft. long, weighing 583 tons, with a 40-ft. stroke, capable of drawing billets of up to 20 tons to a maximum finished wall thickness of 6 in. This machine is used for producing large shell and torpedo-body forgings, accumulator cylinders, superheater headers, large high-pressure steam piping, &c.

Machining and Scrap Reduced by Forging Close to Specifications at Packard. G. F. Daschke. (Heat Treating and Forging, 1941, vol. 27, Oct., pp. 497–498, 515). The author describes some developments in forging practice at the works of the Packard Motor Car Co., Detroit, which have led to less scrap per forging and lower machining costs. In particular the various stages in the press-forging of a

connecting rod fork are described and illustrated.

Stampings Replace Chevrolet Forgings. H. Chase. (Iron Age, 1941, vol. 148, Nov. 20, pp. 64–65). The author describes and illustrates some automobile parts which are now made more rapidly by stamping from strip and do not require machining. Formerly they were forged and had to be machined.

Eccentric-Operated Heading Presses. (Engineering, 1942, vol. 153, Jan. 9, p. 30). An illustrated description is given of an eccentric-operated heading press capable of exerting a pressure of up to 2000

tons.

Relation of Shock in Hydraulic Lines. F. C. Schoen. (Iron and Steel Engineer, 1941, vol. 18, Nov., pp. 33–35). The author describes difficulties which were experienced in the operation of high-pressure hydraulic systems for two forging presses, one a single-cylinder 42-in.dia, ram exerting up to 1800 tons on the dies, and the other a larger press developing a force of 5500 tons on the dies. The troubles consisted of broken fittings and loosened joints caused by shocks in the system at the end of the stroke of the ram. Details are given of the measures taken to deal with these difficulties; they included the installation of choke-valves and heavy spring-balanced shock-valves.

Wire-Drawing Lubricant Circulating Systems. R. C. Williams. (Wire and Wire Products, 1941, vol. 16, Nov., pp. 699–700, 724). The author discusses the requirements of circulating systems for wire-drawing lubricants, and makes the following recommendations: (1) The temperature of a rod-machine lubricant should be 110–130° F., but for fine wire it should not exceed 120° F; (2) the reservoir should be large enough to permit the use of vertical baffle plates, and the rate of flow between the baffles should be slow enough to allow dust and sludge to settle; (3) there should be large draining valves in the bottom of the tank for flushing out; (4) the end of the return line from the machines to the tank should project beneath the surface of the liquid to prevent foaming; and (5) it is essential to have tanks for boiling up compound preparatory to making up fresh solution; for this purpose a steel drum of 55 or 110 gal. capacity will suffice and a steam hose will provide heat and agitation.

ROLLING-MILL PRACTICE

(Continued from pp. 56 A-58 A)

Some Improvement in Steel Plant Maintenance and Design. A. H. Halstead. (Iron and Steel Engineer, 1941, vol. 18, Nov., pp. 36–39). The author describes some improvements carried out by a rolling-mill maintenance department. These relate to oilseals on vertical roller bearings for edging mills, an improved thrust bearing for the vertical spindle of a flanging machine, the use of cup brasses to exclude water and mill scale, and the drilling of lubrication holes in ingot car axles at 45° to the axis instead of at 90°, as it was found that this prevented breakage through the oilholes.

Lignostone Bearings for Rolling Mills. Ya. Gallay. (Iron and Steel Institute, 1941, Translation Series, No. 43). An English translation of a paper which appeared in Stal, 1939, No. 4–5, pp.

45-49. (See Journ. I. and S.I., 1940, No. I., p. 141 A).

The Evolution of the American Rail. C. J. Allen. (Railway Gazette, 1941, vol. 75, Dec. 5, pp. 581–584). The author presents a review of the development of the railway rail in America, including the change from iron to steel, the evolution of the modern American flat-bottom section up to 152 lb. per yd. in weight, and present-day American rolling methods.

The Hot Coil Conveyor. J. E. McBride. (Iron and Steel Engineer, 1941, vol. 18, Nov., pp. 25–29). The author describes and illustrates different designs of conveyors used in continuous wide strip mills to transfer the hot coils from the tilter at the end of the run-out table of the strip mill to either the storage shed, whence they are despatched, or to the uncoiler at the beginning of any subsequent

process. These conveyors must be capable of handling coils of strip up to 100 in. wide, weighing up to 15 tons, at temperatures up to 1200° F., and they must be able to take loads of up to 5000 lb. per linear foot of conveyor.

Electronic Pin-Hole Detection in Sheet Steel. (Machinery, 1941, vol. 59, Dec. 11, pp. 290–291). An illustrated description is given of an apparatus used in sheet and strip mills for detecting minute pinholes in the finished material. The steel strip passes from the side trimmer through the detector to the shears. The detector consists of a source of light above the strip, and photo-electric cells below it. Should there be a pinhole in the strip it will permit light to strike the cell, and thus produce an impulse in the cell circuit. The current impulse is amplified and impressed on the grid circuit of a thyratron valve. The thyratron valve panel may be connected to devices, which either automatically marks the strip, or operates a classifier or sorting machine situated behind the shear which delivers under-gauge, over-gauge and faulty strip into three separate heaps and passes the standard sheets to the piler.

HEAT TREATMENT

(Continued from pp. 94 A-99 A)

The Time Factor in Heat-Treatment Operations. W. Ashcroft. (Metallurgia, 1941, vol. 25, Dec., pp. 35–36). The author discusses the fundamentals of the heat treatment of steel and shows how these

affect the time taken for heating up and quenching.

The Heat-Treatment of Tool Steels. A. J. Schroeder. (Metallurgia, 1941, vol. 25, Dec., pp. 45–49). The author surveys the theory and practice of the annealing, hardening, quenching and tempering of tool steels. It is pointed out that the high temperatures required for the correct hardening of high-speed steel make it necessary to include one or more preheating operations, according to the shape and size of the part. The transfer of the preheated steel to the hardening furnace should take place as quickly as possible and, in the case of molybdenum high-speed steel, it is necessary to cover the tool with borax powder after preheating at 800–850° C. to prevent the formation of MoO, which is detrimental to the properties of this steel.

Surface Structures and Chemistry of Heat Treated 18-4-1 Steel. W. A. Schlegel. (Iron Age, 1941, vol. 148, Dec. 4, pp. 45-50; Dec. 11, pp. 48-59; Dec. 18, pp. 54-58). The author discusses the results of a thorough investigation of the effects of different forms of heat treatment on the composition, micro-structure, scale formation and hardness of 18/4/1 tungsten-chromium-vanadium tool steel. In the first part micrographs of the characteristic structures of this steel

after annealing, after oil-hardening and after oil-hardening and tempering are shown. Specimens quenched in oil after heating in a blacksmith's forge fire were found to be carburised in some parts and decarburised in others. Analyses of the surface material of specimens before and after careful preheating at 1550° F. in reducing, neutral and oxidising atmospheres revealed that the original carbon content of 0.72-0.74% remained practically unchanged. In the second part the results of tests in which specimens were heated to 2300-2450° F. in reducing and in oxidising atmospheres ranging from carbon monoxide 15.8% to oxygen 9.3% after preheating in a reducing atmosphere, are presented and the effects of variations in the temperature, holding time and atmosphere composition are discussed. In the third part the carburisation and decarburisation of specimens with blind holes after treatment in reducing and oxidising atmospheres are examined and the carburising action of molten salt baths is explained. The author's general conclusions are: (1) When this steel is heated for hardening a metaloxide zone is always formed, regardless of the method of heating, this zone is at a minimum when an atmosphere containing 8-12% of carbon monoxide is used; (2) neither carburisation nor decarburisation takes place during preheating at 1500-1600° F; (3) the investigation indicated that this steel may be held at high temperatures for 10 min. in reducing atmospheres without decarburisation occurring; (4) the behaviour of the carburised area during tempering depends on the degree of carburisation and the proportion of retained austenite—this retained austenite can be decomposed to form martensite by retempering; and (5) it was found that the two salt baths used in the investigation were capable of carburising this type of steel.

The Surface Treatment of Metals by Diffusion. I. Stewart. (Mechanical World and Engineering Record, 1941, vol. 110, Nov. 14, pp. 335-337). The author reviews methods of treating nonferrous and ferrous metals to render them wear and corrosion He describes a process of chromium impregnation for steel in which the parts to be treated are packed in a mixture of powdered alumina and metallic chromium and heated in an atmosphere of hydrogen to 1300-1400° C. A steel with less than 0.20% of carbon is suitable for this treatment. Another method is that of packing the parts in metallic chromium or ferrochromium and passing pure dry hydrogen through the container until a temperature of 950-1050°C. is reached; the hydrogen is then by-passed so as to pass through fuming hydrochloric acid, and thence over the ferro-chromium. The chromous chloride formed by the action of the hydrochloric acid gas on the chromium compound exchanges its chromium atoms for iron atoms when it comes into contact with the iron surface.

Surface Hardening of Steel. J. W. Donaldson. (Metal Treatment, 1941, vol. 7, Winter Issue, pp. 131-137, 168). The author

reviews the characteristics of the following methods of hardening the surface of steel; carburising in solid, liquid and gaseous media; nitriding; flame-hardening; hard-surfacing by welding on a layer of wear-resisting alloy; hard chromium plating; and induction hardening. His information is based on recent reports in the technical literature.

Industrial Electric Heat. G. Coley. (Metal Progress, 1941, vol. 40, Oct., pp. 565–569, 572, 573). The author describes and illustrates a number of heat-treatment furnaces for gas-carburising, brazing with copper, and case-hardening with salt baths, all of which are electrically heated. The process of induction heating is

also described and discussed.

Tractor Parts Rapidly Hardened by Induction. E. F. Cone. (Metals and Alloys, 1941, vol. 14, Nov., pp. 687–691). The author describes and illustrates the process of induction hardening as applied to tractor track pins, track roller shafts and driving sprockets. The equipment illustrated is at an American tractor manufacturing plant with a high rate of production. Pins 11 in. long and $1\frac{3}{4}$ in. in dia. pass through the machines at the rate of 225 per hr. and $1\frac{5}{16}$ -in.-dia. pins at 416 per hr. A hardness of Rockwell C 63–67 is obtained and the depth of the hardened zone is about 0·140 in.

Gas Furnaces Become Modern Production Machines. C. G. Segeler. (Metal Progress, 1941, vol. 40, Oct., pp. 575–581). The author reviews developments in the design of equipment for preparing protective atmospheres for annealing and carburising gases

for hardening.

Controlling Atmospheres to Avoid Coloration and Etching. A. G. Hotchkiss and H. M. Webber. (Metal Progress, 1941, vol. 40, Oct., pp. 518-526, 536). The authors discuss how the CO₂/CO and H₂O/H₂ ratios for equilibrium conditions in a heat-treatment furnace atmosphere alter with the temperature, and how these ratios are controlled so as to prevent the decarburisation and oxidation of the charge in or passing through the furnace. They also suggest some methods of detecting the cause of the discoloration which sometimes occurs on heat-treated steel. One method is to put a test-piece of bright copper through the furnace with the steel. Copper is oxidised by oxygen but not by water vapour, so that a comparison of the appearance of the copper and steel indicates whether oxygen or water vapour is responsible. If the former, then air leaks must be looked for. If the latter, the surface cooler of the atmosphere-gas converter should be examined to see if it is functioning properly; the cooling chamber of a continuous furnace should be checked to make certain that it is warm enough to prevent condensation of water vapour on the inner lining. In conclusion methods of heating and cooling are dealt with.

Methane for Gas Carburising. I. Stewart. (Mechanical World and Engineering Record, 1941, vol. 110, Nov. 28, pp. 375–377). The author discusses the principles of gas-carburising with special

reference to the use of methane, butane and propane. He points out that within the furnace the gas is essentially a mixture of hydrogen and hydrocarbons and the ratio of one to the other controls the rate of liberation of carbon; the important thing is to determine that ratio of diluent gas to hydrocarbon gas which will give the maximum rate of carburisation without the deposition of soot. This ratio must be precisely controlled, for slight variations will cause non-uniform carburisation. It is stated that large quantities of methane very suitable for gas carburising purposes are available in Great Britain, and greater use should be made of this gas.

Heating Cylindrical Material in Rolling Radiant Tube Furnace. (Heat Treating and Forging, 1941, vol. 27, Oct., pp. 525–526). A brief description is given of a gas-fired radiant tube furnace specially designed for the heat treatment of cylindrical objects. The special feature of this furnace is the roller hearth, which is constructed so that the parts to be treated lie between two rotating rollers; the parts are thus rotated as they move slowly forward through the furnace, and this ensures that they are uniformly heated. At the discharge end they drop through a sealed chute into the quenching tank.

Uses of Flame Hardening in Machine Tool Production. A. L. Hartley. (Welding Journal, 1941, vol. 20, Oct., pp. 678–686). In the first part of this paper the author describes some research work on the effects of changes in the rate of travel and in the distance of the burner from the work on the microstructure and hardness of steel and cast irons in the flame-hardening process. In the second part he considers the internal stresses set up and the amount of distortion of the parts, and compares this with the distortion of parts carburised in a furnace. In the third part a full description of a universal flame-hardening machine intended for flame-hardening machine-tool parts, especially run-ways, is given. In the concluding part many applications of the machine in the machine-tool industry and some special types of burner are dealt with.

Oxyacetylene Flame Hardening. J. G. Magrath. (Machinist, 1941, vol. 85, Oct. 4, pp. 581–583; Oct. 18, pp. 645–647; Nov. 1, pp. 698–699; Nov. 15, pp. 748–749; Nov. 29, pp. 804–806; Dec. 13, pp. 849–851; Dec. 27, pp. 915–917). In the first of this series of articles the author briefly describes the development of the process of flame-hardening, giving as examples the manual application of the torch for hardening rail ends, and small and large automatic machines for gear teeth and mill rolls. In the second part the technique is described in more detail with information on the gas consumption, speed of travel, depth of hardness and other physical properties of low-alloy steels containing chromium, nickel and molybdenum after flame-hardening. The third part is devoted to a consideration of the properties a steel should have in order to be suitable for flame-hardening. In the fourth part the effect of chromium, manganese, molybdenum, nickel, phosphorus, silicon and vanadium on the flame-

hardenability of alloy steels is dealt with and the surface hardness obtained after flame-hardening a number of these steels is given. In the fifth part some types of carbon cast steel, alloy cast steel and cast iron are described and information on their suitability for flame-hardening is given. The sixth part is devoted to the flame-hardening of alloy cast irons with particular reference to Meehanite. In the seventh part some information is given on the influence of the oxygen/acetylene ratio on the flame temperature, and it is shown that the maximum temperature is obtained with approximately 1.7 parts of oxygen to 1 part of acetylene. Methods of controlling the

depth of the hardened zone are also dealt with.

Dry Cyaniding or Nitro-Cementation. D. McPherson. (Machine Shop Magazine, 1942, vol. 3, Jan., pp. 98–104). The author reviews the work of Cowan and Bryce and of the Russian investigators Vjasnikov, Jurgenson, Braune, Vlasov and Goldina on the nitro-cementation of steel, which is a process of case-hardening by means of a diluted hydrocarbon gas with additions of ammonia. It was observed by the first two of the Russian investigators that nitrogen diffused to a far greater depth than is indicated by microscopical examination, and that it diffused more rapidly into steel than carbon. The last three of the above workers examined the white layer which is characteristic of nitro-carburised parts, and found that this consisted of austenite alloyed with nitrogen. It is pointed out that nitro-carburising is a cleaner and less dangerous process than salt-

bath carburising.

The Determination of the Depth of Decarburisation in Carbon Tool Steel. Yu. V. El'tsin and A. A. Yurgenson. (Zavodskaya Laboratoriya, 1940, No. 7, pp. 745-749). (In Russian). Decarburised specimens of 0.78% and 1.20% carbon steel were prepared by (a) forging and (b) heating for 2 hr. at 1000° C. in a mixture of 80% hematite and 20% carbon. The mechanism of decarburisation in the second case involves diffusion of carbon to the surface as distinct from diffusion of oxygen into the steel in the case of atmospheric decarburisation. Microscopic determination of the depth of decarburisation on annealed specimens always gave consistent results, whilst normalising of decarburised specimens resulted in a reduction of the decarburised zone as seen under a microscope. These observations show that the visible depth of decarburisation is considerably influenced by the temperature at which hot-working is completed, the effect being greater the higher the hot-working temperature. As alternatives to the somewhat lengthy process of annealing, the authors investigated the possibility of determining the depth of the decarburised zone from the difference in grain size obtained after 2 hr. at 950° C. Decarburised zones due to oxygen diffusion developed a finer grain, whilst those due to carbon diffusion developed a coarser grain as compared with the core. The other methods of detecting depth of decarburisation investigated were based on the differential deposition of copper from various reagents, and differen-1942--i

tial rates of oxidation (formation of temper colours) of the decarburised and undecarburised zones.

Annealing Nickel-Chromium Steel Forgings. B. Thomas. (Metallurgia, 1941, vol. 25, Nov., p. 28). The author gives some information on suitable annealing temperatures and cooling rates for forgings of nickel-chromium steels to British Standard Specifications for aircraft material.

The Salt-Bath Method for the Patenting of Steel Wire. D. W. Rudorff. (Metallurgia, 1941, vol. 25, Nov., pp. 7-9). The author reviews developments in the use of salt baths instead of molten lead for patenting steel wire, basing most of his information on a report of an investigation by Lueg and Pomp which appeared in Stahl und Eisen, 1941, vol. 61, Mar. 13, pp. 266-270. (See Journ. I. and S.I.,

1941, No. II., p. 11 A).

Time, Temperature and Size in the Heating of Steel Wire. R. R. Tatnall. (Wire and Wire Products, 1941, vol. 16, Oct., pp. 587-603, 656). The author reports on an investigation of the factors affecting the time required for the heat treatment of steel wire. Tensile tests were made on over 1750 samples of steel wire (carbon 0.57-0.72%), some oil-quenched and others cooled in air, and the rates of heating by radiation in a muffle and by conduction in molten lead were compared. The general conclusions reached were: (1) Conduction heating in lead may be as much as twenty times faster than radiation; (2) the interaction of different heat-transfer processes may cause large changes in the heating time required; (3) heat treatments for particular purposes have their own inherent time values; (4) within the range of analysis of commercial steel. minor variations in carbon and manganese have no effect on the required heating time; (5) cold work has no effect on the time required for heating in either a muffle furnace or a lead bath: (6) cold work decreases the heating time required when the wire is cooled in air from either a muffle or a lead bath—this decrease may be as much as 25% for wire that has been cold-reduced 85%; (7) as the structure varies from fine to spheroidised pearlite the heating time in a muffle may be increased up to 35% with oilquenching and up to 100% with cooling in air; and (8) with radiation heating, wire with a highly reflecting surface requires at least 25% more time than wire with a dull surface.

Heat-Treating Furnaces in the Production Forging Plant. W. Naujoks. (Heat Treating and Forging, 1941, vol. 27, Sept., pp. 452–454; Oct., pp. 499–503). The author describes and illustrates several types of furnaces for the heat treatment of small and medium forgings; the types include car-bottom, oil-fired rotary-hearth, gas-fired chain conveyor and gas-fired pusher furnaces.

The Heating and Heat Treatment of Ordnance. II. Projectile Normalizing, Hardening and Drawing. W. M. Hepburn. (Steel, 1941, vol. 109, Sept. 29, pp. 84–86, 91). The author describes, with drawings and photographs, a number of walking-beam, pusher,

rotary-hearth and continuous conveyor furnaces for the heat

treatment of shells after the forging process.

Heating and Heat Treatment of Ordnance. Section IV. Gun Mounts and Gun Barrels. E. W. Weaver. (Steel, 1941, vol. 109, Oct. 27, pp. 72–73). The author describes a forced-convection carbottom furnace and some very large pit-type furnaces at American naval yards for annealing heavy gun mountings and barrels. (Section III. of this series deals with furnaces for heat treating brass shell cases).

Heat Treating High Explosive Shell. J. McElgin. (Steel, 1941, vol. 109, Dec. 1, pp. 70–74). The author describes some conveyors and continuous and batch quenching systems for the heat treatment of shell forgings, so as to give them the hardness required by United

States ordnance specifications.

Advances in High Explosive Shell Manufacture. (Metal Progress, 1941, vol. 40, Oct., pp. 509–515). An illustrated description is given of the modern heat-treatment installation at the Frankford Arsenal (U.S.A.) for the rapid and uniform hardening and tempering

of shell forgings.

Getting Maximum Results from Carbon and Low Alloy Steels. H. W. McQuaid. (Metal Progress, 1941, vol. 40, Oct., pp. 451–455, 458, 462–471). The author discusses the theory of quenching carbon and low-alloy steels with special reference to the cooling rates and quenching media which will develop the optimum properties. In parts where the stress is greatest at the surface, especially in oil-quenched material, a carbon content close to eutectoid composition will result in surface structures having the best combination of strength and ductility at high hardness, but in small or nonuniform sections the beneficial effects of high carbon are offset by the internal stresses which develop. The importance of proper quenching to obtain the optimum properties, as well as a specified hardness reading, is insufficiently recognised, and more attention should be paid to having adequate jets and circulation for oil-quenching. The author believes that special alloy additions will find their widest application in low-alloy steels containing carbon 0.20-0.45%; these additions are most effective only when used in conjunction with certain melting practices, and these factors must be correctly related. Some S-curves for a number of low-alloy steels and the Jominy endquench test and its application are also discussed, and in conclusion carburising practice for low-carbon steels is dealt with.

Some Notes on S77 Steel. B. Thomas. (Metallurgia, 1941, vol. 25, Dec., p. 44). The author gives an account of some experiments with different forms of treatment, for British Standard Steel S77 for Aircraft Material. This is a 3%-carbon steel containing silicon 0.30% max. and manganese 1.20% max., and trouble had been experienced in obtaining an Izod impact value over the required minimum of 25 ft.-lb. It was found that quenching in oil from 780° C, instead of from 870° C, raised the impact value to about 88 ft.-lb.

It was noted that a higher tempering temperature could be applied after quenching from the lower temperature.

WELDING AND CUTTING .

(Continued from pp. 99 A-100 A)

Heat Flow in Arc Welding. E. M. Mahla, M. C. Rowland, C. A. Shook and G. E. Doan. (Welding Journal, 1941, vol. 20, Oct., pp. 459-S-467-S). The authors investigated the rates of cooling of bead welds down the centre of the surface of steel plates 12 in. X 9 in. of different thicknesses from $\frac{1}{4}$ in. to $1\frac{3}{4}$ in., the position of maximum hardness in cross-sections of the weld and the microstructures of the weld metal and the base metal. Plates of steels S.A.E. 1020, 1035 and 1050 were used. Their conclusions were: (1) For all three steels the hardness increased with both thickness and carbon content, and the point of maximum hardness was in the base metal at the root of the weld; (2) only the $\frac{1}{4}$ -in. plates of steels S.A.E. 1020 and 1035 and the $\frac{3}{4}$ -in. plate of steel S.A.E. 1020 were entirely free from martensite; and (3) the cooling rates in the range 1100-930° F. were approximately 50° F. per sec. for ¼-in.plate, 85° F. per sec. for \(\frac{3}{4}\)-in. plate, 139° F. per sec. for 1-in. plate, and 132° F. per sec. for $l_{\frac{1}{2}}$ -in. plate. The paper concludes with a mathematical analysis in which a formula is developed for predicting cooling rates for certain welding conditions.

Investigation of the Composition of Gases From Arc Welding. V. D. Taran. (Zavodskaya Laboratoriya, 1940, No. 7, pp. 785–787). (In Russian). A simple apparatus for analysing the gases evolved during electric welding is described. The electrodes used are hollow, and thus facilitate the collection of samples of the gas surrounding the arc during actual welding. Analyses of such gas samples obtained from electrodes with different coatings are given. It is pointed out that the volume of gas formed from the electrode coating is several times larger than the volume of the gas sample collected, and there is, therefore, little risk of the sample being

contaminated with air.

The Effects of Plate Temperatures and Variable Wind Velocities on Properties of Carbon Steel Metal-Arc Welds. J. L. Miller and E. L. Koehler. (Welding Journal, 1941, vol. 20, Oct., pp. 499-S-504-S). The authors give an account of their investigation of the effect of wind at different velocities and the effect of initial plate temperatures of 70° and 32° F. on the maintenance of a stable arc. The tests were conducted on fire-box quality steel plate $1\frac{1}{4}$ in. thick with air moving past the arc at zero, 5, 10 and 20 miles per hr. Increasing the air velocity increased the porosity of the weld and the quantity of oxides and nitrides present, and reducing the initial temperature

of the plate also reduced the quality of the weld. The authors are of the opinion that good welds cannot be expected if the arc is exposed

to an air stream moving at more than 5 miles per hr.

The Specification of the Weldability of Steels. A. B. Kinzel. (Welding Journal, 1941, vol. 20, Oct., pp. 483-S-491-S). The author discusses methods of specifying the weldability of steels. These methods involve tests to ascertain: (a) whether the steel melts without undue sparking, spitting or violent evolution of gas; (b) whether the steel is free from laminations; (c) that the steel is not hot-short; (d) that the steel in the strain-aged condition has a notched-bar impact strength exceeding a certain value; and (e) that the minimum notch-bend elongation of a flat bar specimen has a specified value after the sample has been heat treated by continuous cooling to a hardness equal to or greater than that at the centre of an ideally quenched cylinder of the steel when the diameter of the cylinder is less than a specified size.

Weldability Tests of Nickel Steels. C. E. Jackson and G. G. Luther. (Welding Journal, 1941, vol. 20, Oct., pp. 437-S-452-S). The authors report the results of four weldability tests on three series of nickel steels. The first series contained carbon 0.17-0.20% and showed the effect of different amounts of nickel up to 3.63%. the second and third series the nickel content was 2.0-3.5% and the carbon was varied up to 0.40%. The tests applied were: (1) The single-V groove weld test; (2) the T bend test; (3) the Vnotched slow-bend test; and (4) the V-notched impact test; all of these were described in an earlier paper (see Journ. I. and S.I., 1941, No. I., p. 171 A). The use of hardness surveys with a Knoop hardness indenter as an index to the weldability of these steels is also discussed.

Weldable Alloy Materials. (Welding Engineer, 1941, vol. 26, Oct., pp. 42-57). A table is presented in which the manufacturer's name, chemical composition, tensile strength, elongation and welding properties of 317 ferrous and non-ferrous American alloys are

given.

Gas and Resistance Welding the Aircraft Alloy SAE X-4130. H. Lawrence. (Steel, 1941, vol. 109, Nov. 17, pp. 84-85, 88, 90, 100). The author describes the equipment and technique for welding aircraft parts of steel S.A.E. X-4130 by the oxy-acetylene, atomic hydrogen and electrical resistance processes. Several jigs to facilitate welding are described and illustrated, and the heat treatment of

the welded parts is discussed.

An Examination of Three Problems in the Welding of Clad Metals. G. Richter. (Sheet Metal Industries, 1941, vol. 15, Nov., pp. 1427-1434; Dec., pp. 1558-1560). An English translation is presented of an article which appeared in Metallwirtschaft, 1940, vol. 19, Apr. 10, pp. 267-276 on an investigation of the strength and corrosion resistance of butt-welded joints in clad metals. (See Journ. I. and S.I., 1940, No. II., p. 17 A).

MACHINING

(Continued from p. 28 A)

A. Behr. (Metal-Chemical Reactions as an Aid to Machining. lurgia, 1941, vol. 25, Nov., pp. 10-12). The author presents and discusses the results of a Russian investigation by Samartsev and Lavrov in which they studied the influence of aqueous solutions of different electrolytes on the rate of grinding various metals. A glass disc driven by a constant-speed motor was used as a grinder, and as abrasive a suspension of carefully fractionated emery powder in water or in an aqueous solution of an electrolyte was applied. amount of metal ground away in a given time was determined by weighing, and the frictional force between the disc and the metal was measured with a dynamometer. The results when grinding iron showed that the amount of metal ground away varied considerably with each electrolyte, whereas the friction only varied within narrow limits. The grinding rates were greatest with solutions of K₃Fe(CN)₆, Fe₂(SO₄)₃ and CuSO₄. It was observed that the surface of the iron ground in these three solutions did not differ in any way from that ground in water. In the case of nickel and stainless steel the amount of metal ground away varied little from one electrolyte to another, the most effective solutions, however, were KI and K₃Fe(CN)₆. extension of the investigation to the grinding of sintered tungsten carbide revealed that the use of electrolytes speeded up the grinding rate enormously; the highest rate was obtained with a solution of HgNO₂. The various tests established that chemical reactions can make a valuable contribution to the efficiency of machining operations.

A Study of Cutting Oils with and without Added Sulphur. O. W. Boston and J. C. Zimmer. (American Society for Metals, Oct., 1941, Preprint No. 8). The authors report the results of tests undertaken to determine the effect of the presence of active sulphur in a number of different lubricating oils on the cutting speed, tool life and power

required for turning and drilling four S.A.E. steels.

PROPERTIES AND TESTS

(Continued from pp. 107 A-118 A)

Instrumentation—Chief Trends and Some New Data. M. F. Behar. (Metal Progress, 1941, vol. 40, Oct., pp. 623–638, 642). The author reviews developments of the last five years in the design and application of instruments used by metallurgists, in particular instruments devised for the measurement and control of pressure, temperature and gas composition, and for recording the results of

mechanical tests. It is pointed out that instrumentation has become a science with its own problems and technique, a study of which is essential to enable the correct selection of a type of instru-

ment for a particular purpose to be made.

Cast Iron in Light Structural Parts. A. Thum, K. Sipp and O. Petri. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Jan., pp. 319-322). The authors describe an investigation of the strength of iron castings with wall thicknesses of 6-30 mm. The object was to obtain information on the minimum thickness compatible with the necessary rigidity for machine tool parts. Irons with 3.2-3.6% of carbon and 1.4-2.5% of silicon were used. It was found that pearlitic cast irons had little susceptibility to wall thickness, whilst irons of lower strength were more susceptible. It was confirmed that with increasing carbon plus silicon content the wall-thickness susceptibility increased. A suitable analysis for castings with walls 6-30 mm. thick was one with 4.80-5.30% of carbon plus silicon. Internal stresses could be relieved by annealing at about 600° C. without any noticeable change in the strength. It was found that it was not always possible to judge the strength of a casting from a cast-on test-piece, for in one case a 30-mm.-dia. piece which had been cast on a wall of the same thickness was satisfactory, but when this size piece was cast on a 12-mm, wall the strengths of the wall and the test-piece were very different.

Evaluation of the Static Ductility of Metals. Ya. B. Fridman. (Zavodskaya Laboratoriya, 1940, No. 7, pp. 761–775). (In Russian). The author discusses in detail the problem of the choice of either the relative elongation or the reduction of area as a measure of the ductility of a metal or alloy, because progressive alloying of a metal may have opposite effects on these two values which are at present used rather indiscriminately as criteria for ductility. The work expended in static deformation and the relation between the different variables involved are also considered and experimental data are

presented.

A New Method for Determination of Stress Distribution in Thin-Walled Tubing. G. Sachs and G. Espey. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1384: Metals Technology, 1941, vol. 8, Oct.). The authors describe a method of determining the distribution of residual stresses in thinwalled tubing by extending the simple splitting and slitting methods to samples from which successive surface layers have been removed by pickling or machining. The pickling can be done either before or after the splitting. In the latter case a single specimen may serve for each set of experiments, whilst the former procedure requires a separate specimen for each measurement. The paper is mainly mathematical, with examples of the calculations for evaluating the stresses.

Fatigue Strength Improved by Flame Treatment. O. J. Horger and T. V. Buckwalter. (Iron Age, 1941, vol. 148, Dec. 18, pp. 47-

53). The authors give an account of their investigation of the fatigue strength of a hollow axle and wheel assembly with the object of comparing the fatigue strengths after press-fitting wheels on axles in the hot-rolled, the quenched and tempered, and the flame-hardened states. The axles were 7 ft. $4\frac{1}{2}$ in. long, with the outside diameter varying from $6\frac{1}{2}$ in. to $7\frac{9}{16}$ in., and $4\frac{1}{2}$ in. in inside dia. It was found that the endurance limits of flame-hardened shafts were very much higher than those in the as-rolled or quenched and tempered condition. The influence of residual stresses on the fatigue strength was also examined, and it was observed that as-rolled and flame-hardened hollow axles had residual compressive stresses in the surface, and that these had higher fatigue strengths than quenched and tempered axles which had residual tensile stresses in the surface. It is suggested that further research on the relation between fatigue strength and residual stress is needed.

Resonant Vibration Testing. R. O. Fehr and C. Schabtach. (Steel, 1941, vol. 109, Nov. 10, pp. 64, 65, 96, 102). The authors describe various magnetic methods of exciting mechanical vibrations for high-speed fatigue tests on parts of various size and shape. The principles are explained and some variable-frequency apparatus for

testing turbine rotors are described and illustrated.

Effect of Clamping on the Fatigue Strength of Unalloyed Steel. H. Cornelius and F. Bollenrath. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Jan., pp. 335-340). The authors describe a special method of clamping for holding specimens during tensile-fatigue tests, and discuss the effects of the clamping pressure and the metal of which the clamps are made on the frettage corrosion (or oxidation loss) and the fatigue test results. Flat test-pieces of a 0.33%carbon steel were used, together with pairs of clamps made of a 0.35%-carbon steel, 70/30 brass and a chromium-nickel-molybdenum steel. With all the clamping materials it was found that the oxidation loss at first increased and then decreased very rapidly with increasing pressure on the clamps. No particular fatiguestrength value could be related to high oxidation loss, as both the loss and the reduction in section increased with increasing number of oscillations. Increasing the clamping pressure reduced the fatigue-strength values, the relation being almost linear. With low pressures the effect of the oxidation loss was the predominating factor, whilst at high pressures the peak pressure was the decisive factor.

Hadfield Manganese Steel. V. R. Farlow and L. H. McCreery. (Metals and Alloys, 1941, vol. 14, Nov., pp. 692–696). The authors present the results of an investigation of the effects of two methods of cold-reduction on the hardness of steel containing carbon $1\cdot15\%$ and manganese $11\cdot6\%$. Specimens $0\cdot5\times0\cdot5\times0\cdot237$ in. were prepared, and these were reduced 2%, 4%, 17%, 25% and 42% by impact; other specimens were reduced 2%, 4% and 17% under compression by static loading. The hardness of the cold-worked surfaces and of sections of the specimens was determined before and

after various forms of heat treatment. Within the errors of measurement the surface and centre hardnesses were the same, and it was observed that like deformation produced like hardness and structure, irrespective of the method of compression. When the steel had been cold-reduced 4% before heat treatment at 800° F. the critical cooling rate was such that some carbide precipitation occurred, although increased hardening and more precipitation had occurred with the slower cooling rate at the centre. After 17% cold-reduction the carbide-precipitation tendency was so great that the rapid cooling rate at the surface was no more effective than the slower rate at the centre in preventing carbide precipitation. The investigation was carried out to determine the suitability of manganese steel for certain types of bearings.

The Measurement of Rockwell Hardness on a Spherical Surface. A. G. Spektor. (Zavodskaya Laboratoriya, 1940, No. 4, pp. 455–460). (In Russian). The author has derived the following formula for determining the hardness of a spherical surface by the Rockwell

method:

$$R_{c}(sph) = R_{c} + rac{1.312R_{c} - 0.0065R_{c}^{2} - 67.5}{R}$$

where $R_c(sph)$ is the apparent Rockwell hardness measured on the spherical surface, R_c is the true Rockwell hardness and R the radius of curvature. Experiments on steel balls showed that the calculated results were correct up to R=6.5 mm. For larger values of R (6.5-11 mm. and 11-15 mm.) the error amounted to 0.5 and

1 Rockwell C unit respectively.

Investigation of the Thermal Expansion of some Metals and Alloys with an Improved Dilatometer. H. Esser and H. Eusterbrock. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Jan., pp. 341-355). After pointing out some disadvantages of the optical dilatometers of Chevenard and Bollenrath, the authors describe an improved optical dilatometer which they developed. This new instrument requires a shorter specimen than the others and has simplified bearings. With this instrument they studied the expansion properties of several non-ferrous metals, carbonyl iron, electrolytic iron and six iron-carbon alloys with 0.13-1.12% of carbon. The coefficients of expansion at temperatures up to 1000° C. were determined and compared with that of gold. The transformation temperatures and the changes in length due to the transformation of the iron and iron-carbon alloys are presented in tables.

The Determination of the Creep Strength of Steel at Temperatures above 600°. A. Krisch. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Jan., pp. 325-332). An abridged account of a previously published investigation by Pomp and Krisch on the creep strength of heat-resisting steels at 600°, 700° and 800° C. is presented. (See Journ. I. and S.I., 1941, No. II., p. 222 A).

Investigation of the Behaviour of Metals under Deformation at High Temperatures. Part II. Structural Changes in Carbon Steels Caused by Creep and Graphitisation. C. H. M. Jenkins, G. A. Mellor and E. A. Jenkinson. (Iron and Steel Institute, 1942, this Journal, Section I.). A study was made of the behaviour of carbon steels by means of the microscopical examination of test specimens from short-time (tensile) and long-time creep tests. The specimens were tested in a high vacuum over the temperature range $15-950^{\circ}$ C. In the majority of cases the stress applied was sufficient to cause rupture. The materials examined had various carbon contents up to $1\cdot14\%$.

The effect of the carbon content was most noticeable in short-time (tensile) tests, but as the temperature of test was increased this effect was reduced. In creep tests at a temperature of 450° C, there was a marked difference in the life of the specimens of certain materials, those of high carbon content showing the greatest strength. At 550° C, and above, the effect of this element on the life in creep tests was not very noticeable. The $\alpha\!-\!\gamma$ structural change in iron and low-carbon steels between 700° and 900° C, caused a marked increase in the strength of the material as measured by short-time (tensile) tests, but in high-carbon steels there was little alteration in properties

resulting from this structural change.

The work shows the general weakening of the material with increase of temperature and describes the nature of the structural changes set up. The deformed material gave evidence of slip and dislocation as well as recrystallisation, spheroidisation, graphitisation and cracking. The various materials showed these effects to varying degrees, depending on their chemical compositions.

The deformation of ferrite occurred by the well-known action of slip, but a new mode of deformation is described in regard to the constituent pearlite. This is referred to as dislocation. It appears that the pearlite can be deformed by a shearing action on a plane

inclined to the ferrite and carbide lamellæ of the pearlite.

The tests were made principally on high-carbon steels in which recrystallisation of the ferrite was not so prominent a factor in their deformation as in the low-carbon steels described in an earlier paper. On account of the higher proportion of pearlite in these high-carbon steels spheroidisation was an important feature. In certain cases rapid spheroidisation was seen even in short-time (tensile) tests, on account of the accelerating influence of deformation. Spheroidisation might occur very locally in a test specimen, and this gave rise to appreciable softening and a sudden fracture of the specimen. The reduction of area was relatively high, considering the degree of elongation in these cases.

Graphitisation, which needs a longer time than spheroidisation to make its appearance, was also of common occurrence in high-carbon materials, particularly below the critical range (A_1-A_3) . The formation of graphite was found in the highly deformed material

near the fracture in creep tests at a temperature as low as 450° C. The graphitic areas so formed acted as centres of weakness at which cracks developed in stressed specimens. Graphitisation was less pronounced above the A_1-A_3 range than below it, occurring only in the steels of highest carbon content. It appeared to assist the development of intercrystalline cracking, which was observed above this range. The present work shows that steels referred to as rapidly graphitising offer, in general, a poor resistance to creep and spheroidise

rapidly.

Hvdrogen Embrittlement. H. J. Noble. (Iron Age, 1941, vol. 148, Nov. 27, pp. 45–52). The author presents and discusses the results of tests on the sensitivity of steel to hydrogen embrittlement. In most of the tests the brittleness was induced by descaling the steel specimens by the Bullard-Dunn process. In this process the part is degreased in an alkali, and it is then made the cathode in a bath containing 10% sulphuric acid and a little tin. The hydrogen which is liberated lifts off the scale and a tin film is deposited on the clean steel, which protects it from further attack. The author's conclusions were: (1) Sensitivity to hydrogen embrittlement in general increases with hardness; (2) the maximum sensitivity exists if the steel has been tempered in the 500-550° F. range, except in the case of molybdenum steel; (3) the sensitivity increases with the amount of hardening constituent, particularly carbon; (4) the degree of embrittlement decreases on ageing at room temperature, and this can be accelerated by heating; (5) the temperature of the heat treatment has a much greater effect than the holding time on the embrittlement sensitivity; (6) the embrittlement increases with decreasing section; and (7) there is practically no hydrogen embrittlement in steels which have been heat treated to a hardness of Rockwell C 40.

Nitrogen for Nickel in Cr-Ni Steels. W. Tofaute and H. Schottky. (Iron Age, 1941, vol. 148, Nov. 13, pp 39–43). An abridged English translation is presented of a paper which appeared in Archiv für das Eisenhüttenwesen, 1940, vol. 14, Aug., pp. 39–43. (See Journ. I.

and S.I., 1941, No. II., p. 223 A).

The Art of Alloy Engineering. P. D. Merica. (Burgess Memorial Lecture: Metal Progress, 1941, vol. 40, Oct., pp. 425-440). The author reviews improvements which have been developed in methods of fabricating ferrous and non-ferrous alloys and in enhancing their mechanical properties. He points out that improving some properties is often combined with the deterioration of others, and this has led to compromises, with the result that there are to-day more than 5000 different alloys and steels in commercial use. The developments in grinding and welding, and the manufacture of special alloys suitable for these processes show that major changes in engineering technique in any field have a great influence on the trend of development in alloy materials. Some possibilities in the development of powder metallurgy are also discussed.

Alloy Additions to Gray Cast Iron. G. A. Timmons and V. A. Crosby. (Foundry, 1941, vol. 69, Oct., pp. 64–66, 145–147; Nov., pp. 63, 144–147). The authors give an account of their investigation of the effect of additions of chromium, molybdenum, copper, nickel and vanadium on the properties of an ordinary grey cast iron containing about 3.25% total carbon in the as-cast condition and after various forms of heat treatment. The additions were made in the ladle, and as far as possible the melting and casting conditions were kept equal. The tests were made according to A.S.T.M. standards. Particular attention was paid to the effect of the alloying elements on the softening of the iron by heat treatment at different temperatures. The irons containing chromium offered the greatest resistance to hardening breakdown at temperatures in the 1100-1400° F. range. After annealing at 1400° F. the chromium-molybdenum iron possessed the highest hardness and highest tensile strength; the tensile strength of this iron was not reduced by the heat treatment, although the hardness fell from 262 to 217 Brinell. A comparison of the microstructures after annealing at 1400° F, with the original structures revealed how the pearlite had spheroidised and the migration of the carbon to the graphite flakes.

On Heat Resistant and High Tensile Alloy Cast Iron. T. Saito. (Suiyokwai-Shi, 1941, vol. 10. Sept. 25, pp. 541–568). (In Japanese). The author reports the results of the effect of additions of silicon, nickel, copper, phosphorus, tungsten, molybdenum, manganese, vanadium, chromium and sulphur on the tensile strength, hardness and microstructure of cast irons containing 2.5% and 3.5% of

carbon at 600°, 700° and 800° C.

Lowering the Cobalt Content of Alloys for Welded Coatings. M. Schmidt, W. Lamarche and E. Kauhausen. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Jan., pp. 357-362). An investigation of the structure and hardness of the cobalt-chromium-tungsten allovs which are used as welding rods to make heat- and corrosionresisting facings (such as stellite) on steel has revealed that they attain their maximum hardness after cooling from 1200-1300° C. with subsequent annealing at 800° C. for 10-72 hr., and that this is due to a precipitation of carbides. In the present paper the authors describe their investigation of the properties of alloys containing less cobalt and additions of iron, nickel and molybdenum. reducing the cobalt from 65% to 27% it was found that no transformation took place on cooling; but with still less cobalt a transformation occurred at a temperature which depended on the amount of cobalt. The hardness at high temperatures decreased with decreasing cobalt content. The addition of nickel resulted in a * stable non-transforming structure even with only 11% of cobalt and 5% of nickel, and decreased the hardness at both room and high temperatures. The addition of molybdenum was very promising. and 4-5% of this element with 19% of cobalt produced an alloy with properties practically equal to those of any non-ferrous alloy.

Study on the High Speed Tools. H. Hotta. (Tetsu to Hagane, 1941, vol. 27, June, pp. 373–405). (In Japanese). The author discusses how the degree of reduction by forging affects the hardness, microstructure and cutting efficiency of high-speed steel tools. He also describes two methods of producing sintered tungsten-carbide tools.

Substitution of Molybdenum for Tungsten. (Mechanical Engineering, 1941, vol. 63, Nov., pp. 798–800). In this paper particulars are given of the properties and analyses of high-speed steels containing 6% max. of tungsten and 9% max. of molybdenum, with some chromium and vanadium, which can be used as substitutes for the 18%-tungsten steels. Some molybdenum-steel substitutes for low-tungsten tool steels and die steels are also listed. The information is based on a report of the Advisory Committee on Metals and Minerals of the National Research Council (U.S.A.).

How Vanadium Influences Design Materials. C. N. Dawe. (Machine Design, 1941, vol. 13, Oct., pp. 49–53, 110–112). The author presents four comprehensive tables giving the analyses, heat treatment, applications and properties of four classes of vanadium steels as used in the United States. The four classes are: (1) Wrought vanadium steels in heavy sections; (2) wrought vanadium steels in light sections; (3) vanadium spring steels: and (4) vana-

dium cast steels.

Low Alloy Steel Castings from Available Raw Materials. C. H. Lorig. (Metals and Alloys, 1941, vol. 14, Nov., pp. 712–717). The author presents and discusses tables and curves relating to the analyses and properties of low-alloy cast steels containing not more than $2\cdot15\%$ of nickel, up to $1\cdot68\%$ of manganese and some with small percentages of chromium, molybdenum, vanadium, silicon and

copper, either separately or combined.

Graphitic Steels. F. R. Bonte. (Steel, 1941, vol. 109, Nov. 24, pp. 80–82, 96–100). The author gives some information on the manufacture, heat treatment and properties of five types of graphite-bearing steel, known as Graph-Sil, Graph-Mo, Graph-Tung, Graph-Al and Graph-M.N.S., all of which contain about 1.50% total carbon. The unalloyed steel Graph-Sil should contain at least 0.90% combined carbon, and the graphitising practice is to normalise it from 1600° F., reheat it to 1450° F. and cool in the furnace at about 40° F. per hr. through the critical range to 1100° F. and then to cool in air. This treatment produces a hardness of 170–190 Brinell.

"Graphitic" Steels... Some of Their More Important Applications. F. R. Bonte. (Steel, 1941, vol. 109, Dec. 1, pp. 96, 111, 112). The author discusses some applications of the five types of graphitic steel referred to in an earlier paper (see preceding abstract); these include metal spinning rolls of Graph-Sil, blanking and forming punches of Graph-Mo, cold-drawing dies of Graph-Tung

and mandrels of Graph-M.N.S.

British Standard Specification for Round Strand and Flattened Strand Steel Wire Ropes for Colliery Winding Purposes. (British

Standard Specification No. 236-1941).

British Standard Specification for Round Strand and Flattened Strand Steel Wire Ropes for Colliery Haulage Purposes. (British Standard Specification No. 330–1941).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 118 A-126 A)

The Radiographic Examination of Heavy Plate. O. R. Carpenter. (Welding Journal, 1941, vol. 20, Oct., pp. 717–723). The author considers the application of X-rays for examining welds in steel plate up to $5\frac{1}{2}$ in. thick and describes equipment using up to 1000 kV. Means of controlling secondary radiation are dealt with, and the technique for obtaining good radiographs with 1000-kV. equipment

is given.

On the Nature of a Satellite in the X-Ray Pattern of α -Crystals, and the Differentiation of a New Phase α' by the Surface Recrystallization Method in Certain Ternary Alloys. Part I. The Iron-Nickel-Aluminium System. S. Kiuti. (Report of the Aeronautical Research Institute, Tokyo Imperial University, 1941, vol. 16, Apr., pp. 167–204). In view of the importance of the discovery of a new α' -phase in the magnetic iron-nickel-aluminium system (see Journ. I. and S.I., 1941, No. II., p. 142 A), the author reports in the present paper some of the experimental data he obtained in the course of his early studies of this new phase. In these studies the possibility of differentiation of the new phase α' by the surface-recrystallisation method was considered theoretically and verified experimentally by X-ray analysis. The conclusion from calculations was that the α' -phase is a body-centred cubic lattice with a simple cubic superstructure of the CsCl-type.

An X-Ray Study on the Mechanism of the Splitting Phenomenon of α -Crystals in the Interiors of Some Ternary Alloys. Part I. The Iron-Nickel-Aluminium System. S. Kiuti. (Report of the Aeronautical Research Institute, Tokyo Imperial University, 1941, vol. 16, May, pp. 271–298). The author refers to the separation of the new α' -phase discovered in the surface layers of magnetic ironnickel-aluminium alloys (see preceding abstract), and now reports on his study of the problem whether the same phase occurs in the interior of the specimens. After subjecting specimens to prolonged annealing at a constant temperature, the splitting of the α -crystals was found by X-ray examination to have taken place in the interior also, and this confirmed the author's earlier conclusion obtained by

the surface-recrystallisation method.

A Magnetic Determination of the A3 Transformation Point in Iron. B. A. Rogers and K. O. Stamm. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1388: Metals Technology, 1941, vol. 8, Oct.). The authors describe an investigation of the A2 point of samples of very pure iron with a magnetic balance apparatus which was used on a previous occasion for determining the magnetic behaviour of slags (see Journ. I. and S.I., 1940, No. I., p. 206 A). The conclusions drawn from the results obtained were: (1) The Ac₃ transformation of iron of high purity is complete at a fixed temperature, which is in the vicinity of 910.5° C. At this temperature the rate of transformation is so slow that several hours are required for the $\alpha \rightarrow \gamma$ change. An increase of about 1° C. causes the change to take place much more rapidly; (2) the Ar₃ transformation in iron occurs at about 902.5° C, and its velocity is three or four times that of the Ac₃ transformation; (3) the minimum temperature difference between Ac, and Ar, found in the present investigation was 8° C; (3) the presence of a small amount of oxide causes the Ac₃ transformation to begin several degrees below its normal temperature and to end several degrees above it. The Ar, transformation is less affected by oxides; (5) the transformation velocity is at its maximum when about half the material has been transformed, and the velocity near completion is much less than that near the beginning; and (6) if the temperature is reduced to 907° C. before the Ac₃ transformation is complete, the iron reverts to the α state. If the temperature is raised to a point between 903° and 907° C. before the Ar₃ transformation is complete, the magnetic susceptibility continues to rise slowly for a short time and eventually ceases.

The Positions of the Carbon Atoms in Austenite. N. J. Petch. (Iron and Steel Institute, 1942, this Journal, Section I.). By careful photometric work direct X-ray evidence of the location of the carbon atoms in austenite has been obtained. They are found to lie at the centres of the unit cells and at the mid-points of the edges, these positions being the centres of the largest spaces between

the iron atoms in the austenite structure.

There is never enough carbon in solution for every one of these positions to be filled. The number of carbon atoms per unit cell varies from zero for pure iron to 0.32 for a 1.7% carbon steel, so that, at the most, only one possible position in twelve is occupied.

Other theories of the structure of austenite are discussed in the

light of these results.

The S-Curve of a Chromium-Nickel Steel. B. M. Loring. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1383: Metals Technology, 1941, vol. 8, Oct.). By making hardness measurements, dilatometer observations and examinations of the microstructure, the author constructed Scurves for an oil-hardening steel containing carbon 0.29%, nickel 3.25% and chromium 1.45%. A comparison of the results indicated

that the maximum difference in the beginning of transformation as measured by the different methods amounted to about 10% of the total holding time. An extremely slow rate of reaction for the lamellar transformation was found at 510° C. The dilatometer observations gave evidence of what has been called a two-stage reaction in the low-temperature transformation of austenite.

The Use of Motion Pictures for the Study of Structural Transformations in Metals and Alloys on Heating and Cooling. S. M. Palestin. (Zavodskaya Laboratoriya, 1940, No. 7, pp. 742–745). (In Russian). The use of Esser's arrangement for high-temperature microscopy in the preparation of films of transformations in metals and alloys for educational purposes is briefly described. Microstructural changes were filmed at the rate of one frame per second, a temperature scale being included in the photographs. Films obtained showing the transformations in mild steel (carbon 0·07%) and in hypereutectoid steel (carbon 1·5%) and of the graphitisation of white cast irons as well as changes in a 12% aluminium bronze are described.

Precipitation Hardening in the Fe-W System. C. S. Smith. (Journal of Applied Physics, 1941, vol. 12, Nov., pp. 817–822). An X-ray study has been made of precipitation-hardened iron-tungsten alloys containing $7\cdot16\%$ of tungsten. It is concluded that the precipitation reaction is of the discontinuous type. On the basis of the evidence obtained by X-ray diffraction methods a mechanism for the formation and growth of the precipitate is proposed and a picture of the crystallographic form of the precipitate is deduced.

CORROSION OF IRON AND STEEL

(Continued from pp. 126 A-128 A)

The Corrosion of Steel and Various Alloys by High Temperature Steam. H. L. Solberg, G. A. Hawkins and A. A. Potter. (Journal of the American Society of Naval Engineers, 1941, vol. 53, Nov., pp. 705–723). The authors describe an investigation of the influence of steam temperature and pressure and of the exposure time on the corrosion of a $0\cdot10\%$ -carbon steel, a carbon-molybdenum steel, several chromium-molybdenum steels, a 12%-chromium steel and 18/8 stainless steel. Their general conclusions were: (1) The resistance of alloy steels to high-temperature steam is greatly influenced by the amount of chromium present; alloy steels containing 7% or more of chromium are very resistant to the attack of steam at temperatures up to 1400° F. (2) 18/8 stainless steel remains practically unaffected by steam at 1400° F. (3) The rate of corrosion is fastest during the first 500 hr. of testing and then it gradually diminishes as the time of exposure to steam continues. (4) The

rate of corrosion increases with the steam temperature and, except for steels with more than 7% of chromium, the increase is very rapid at temperatures above 1100° F. (5) The steels tested may be grouped into the following three general groups according to the type of scale formed: (a) low-carbon, low-chromium and carbon-molybdenum steels which become covered with a thick, porous, tightly adhering scale, (b) 4-6%-chromium steels and chromium-molybdenum-aluminium-silicon steels on which a very brittle scale forms which flakes off under fluctuating temperatures, and (c) steels with 7% min. of chromium on which a very thin, non-porous, tightly adhering scale is formed. (6) Changes in the steam pressure between 100 and 1200 lb. per sq. in. do not affect the rate of corrosion.

Studies in Corrosion Control. H. P. Stockwell jun. (Journal of the American Water Works Association, 1941, vol. 33, Aug., pp. 1409–1428). The author describes tests made to obtain information on the problem of corrosion control in the treatment of water for the Qttawa municipal supply, and to obtain data on the relative corrosion resistance of various metals used for household piping.

Experiences with Cathodic Protection of Water Tanks. J. C. Keith. (Journal of the American Water Works Association, 1941, vol. 33, Sept., pp. 1503–1516). The author reviews the present position in the United States of the development of the cathodic protection technique for the protection of water tanks against corrosion. A recent questionnaire sent to owners of tanks fitted with this system revealed that it was entirely satisfactory in 73% of the tanks, unsatisfactory in 13% and of doubtful value in 14%. Most of the unsatisfactory cases were due to ice interference during the winter season. Some data on the current consumption of installa-

tions on different sizes of tank are given.

Progress in Water Conditioning Methods to Inhibit Corrosion. (Journal of the American Water Works Association, 1941, vol. 33, Sept., pp. 1534-1540). The paper is a report by the Committee on Water Conditioning Methods to Inhibit Corrosion appointed by the American Water Works Association, in which an outline of its present and proposed future activities is presented. It is pointed out that any change in the method of treating water is liable to upset the very delicate chemical and biological equilibrium which exists in all distribution systems, and serious trouble due to change in treatment should not be regarded as a deterrent to the trial of new treatment methods. It is stated that about 150 plants are using sodium hexametaphosphate in soft water for the control of corrosion and only about 3% or 4% of these have experienced any trouble in their distribution systems. Some results of experiments on the solubility of lead carbonate in water treated with metaphosphates are quoted. These showed that this treatment considerably increased the solubility, but the Committee does not regard the results as conclusive.

Chromate Corrosion Inhibitors in Bimetallic Systems. M. Darrin. (Industrial and Engineering Chemistry, Analytical Edition, 1941,

vol. 13, Nov., pp. 755–759). The author reports on an investigation of the corrosion-inhibiting properties of sodium chromate and sodium bichromate when added to industrial water systems. Tests were made with iron, galvanised iron, tinned iron, copper, brass and aluminium, both alone and in contact with each other. It was observed that sodium chromate and bichromate are effective in retarding, or completely inhibiting, the corrosion of many bimetallic systems in water. Sodium chromate and bichromate are effective in retarding corrosion in most monometallic systems. Sodium bichromate also reduces corrosion in many bimetallic systems, but is not so generally effective as sodium chromate. The relative retardation of corrosion by sodium chromate is essentially the same in hot and cold water. Although the rate of corrosion of most systems is greatly accelerated by aeration, there is no important difference between aerated and closed systems when sodium chromate is present.

The Influence of Corrosion on Propeller Shaft Maintenance. H. L. Setz. (Journal of the American Society of Naval Engineers, 1941, vol. 53, Nov., pp. 735-744). It is common practice in the maintenance of ships' propeller shafts to reduce the diameter by machining in order to remove corrosion pits from which fatigue cracks would grow. In the present paper the author describes a series of tests on several steel shafts ranging from 3 in. to 12 in. in dia. before and after reducing the diameter by \(\frac{1}{8} \) in., \(\frac{1}{4} \) in. and \(\frac{1}{2} \) in., from the results of which the average stress values and factors of safety were calculated. The results of earlier corrosion-fatigue tests on similar steels are quoted (see Journ. I. and S.I., 1939, No. I., p. 111 A) and a comparison is made between the reductions in the safety factors resulting from (a) the decrease in the shaft diameters without altering the conditions of loading, and (b) the corrosion fatigue. The author's general conclusion is that any reduction in shaft diameter to remove a corroded surface is to be recommended, provided that the resulting safety factor is higher than 7.

Atmospheric Corrosion of Structural Steel, and Paint Protection. (Symposium on Atmospheric Corrosion: Journal of the Institution of Engineers, Australia, 1941, vol. 13, Sept., pp. 221–225). In the introduction to this brief symposium A. M. G. Dempster gave some information on the atmospheric conditions in Australia and their influence of the corrosion of structural steel. It is apparent that in many districts the corrosion is so slight that the painting of steel is not economically justified. The introduction was followed by a paper on "Preparation of Steel Surfaces" by S. R. J. Davison, and another entitled "Paint Characteristics" by J. H. Hesketh. In the former the causes of corrosion and the nature of mill scale are briefly explained and the use of a descaling bath containing a medium with a phosphoric-acid base is advocated. In the paper on paint characteristics, the author explains the functions of priming and finishing coats and the corrosion-inhibiting properties of red lead

and zinc chromate.

Experimental Cooling Systems. D. W. Haering. (Industrial and Engineering Chemistry, Industrial Edition, 1941, vol. 33, Nov., pp. 1360–1365). The author discusses the treatment of cooling water to prevent the corrosion of steel tubes and describes a simple form of experimental cooling system six of which were erected in one laboratory so that six experiments could be run simultaneously under identical atmospheric conditions. Each system had a small wooden cooling tower, a heat exchanger with an immersion heater, two thermometers and a circulating pump. Two preliminary studies are described the purpose of which was to establish the relation between results from these small units and

the experience with full scale equipment.

Scale and Corrosion Studies. D. W. Haering. (Industrial and Engineering Chemistry, Industrial Edition, 1941, vol. 33, Nov., pp. 1365-1369). In this paper the author describes some scale and corrosion tests using the six small-scale cooling systems described in an earlier paper (see preceding abstract). Data were obtained by analysing and weighing the deposit on the immersion heater, by analysing the water and determining its pH value. The effects of different inhibitors were studied and the following conclusions were arrived at: (1) Scale formation and control are influenced by the concentration of dissolved solids in the water; (2) the glucoside derivatives are more effective in inhibiting either scale or corrosion than hexametaphosphate; (3) iron contents, either in water or in deposits, cannot be used for accurate interpretation of corrosion rates in recirculating cooling systems; (4) the chloride concentration is an accurate indicator of the concentration of dissolved solids in cooling-system practice; and (5) the rate of corrosion in cooling systems is directly affected by the chloride concentration of the water

ANALYSIS

(Continued from pp. 74 A-79 A)

The Determination of Gases in Samples of Molten Steel in the Course of a Heat by the Hot-Extraction Method. P. S. Lebedev. (Zavodskaya Laboratoriya, 1940, No. 4, pp. 436–444). (In Russian). During the solidification of 1–2 kg. samples of steel, ferrous oxide is completely reduced by the carbon and the carbon monoxide extracted. Manganous oxide is only partially reduced, whilst there is no reduction of the more stable oxides of silicon, chromium, titanium and aluminium. Dissolved carbon monoxide, hydrogen and nitrogen are probably more or less completely extracted. Very serious errors may be caused by the presence of rust on the walls of the apparatus in which the gases are extracted from the molten steel. Errors in both oxygen and nitrogen contents may arise

through leakage of air into the vacuum pipette before the sample of steel is introduced, and some of the carbon monoxide extracted may be decomposed by aluminium or manganese volatilising from the steel and condensing on the cooler parts of the apparatus. The latest type of vacuum pipette developed by the author is described and illustrated. It is characterised by portability, light weight (8 kg.) and especially by the ease with which the interior may be cleaned to remove rust. The gases extracted are finally collected in a glass vessel which can be detached from the apparatus and attached to any suitable gas analyser. Vacuum pipettes developed by other investigators are critically reviewed and their drawbacks, especially difficulty of cleaning and wastage of seamless tubing in some types, are pointed out. The errors arising out of inefficient cleaning are demonstrated by experimental results.

The Effect of the Vaporisation of Iron on the Determination of Oxygen in Ferro-Tungsten by the Hot-Extraction Method. G. Thanheiser and R. Paulus. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Feb., pp. 381–390). The paper which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 14, pp. 217–228, is reproduced. (See p. 75 A). (See also Iron

and Steel Institute, 1942, Translation Series, No. 67).

Automatic Determination of Carbon Monoxide in Hydrogen-Containing Gas Mixtures. A. I. Eterman and I. S. Afanas'ev. (Zavodskaya Laboratoriya, 1940, No. 4, pp. 444–447). (In Russian). The authors describe a method of determining the carbon monoxide in gas mixtures containing hydrogen. The carbon monoxide is reduced quantitatively to methane by passing it over a heated nickel-aluminium catalyst. The gas analysis apparatus used is described.

A Comparative Investigation of Methods of Determining the Nitrogen Content in Steel and in Alloys. G. Phragmén and R. Treje. (Iron and Steel Institute, 1942, Translation Series, No. 61). An English translation of a paper which appeared in Jernkontorets Annaler, 1940, vol. 124, No. 9, pp. 511–531. (See Journ. I. and S.I.,

1941, No. I., p. 140 A).

Method for the Accurate Determination of Small Contents of Carbon in Steel. M. G. Zhuravleva and G. I. Chufarov. (Zavodskaya Laboratoriya, 1940, No. 5–6, pp. 498–499). (In Russian). In the authors' method for determining low carbon contents in steel the sample is burnt in oxygen at 1200° C. and the carbon dioxide and sulphur dioxide are condensed in a liquid-air trap. They are determined together by allowing them to evaporate into an evacuated vessel and measuring the increase in pressure. They are then recondensed and the carbon dioxide is rapidly distilled off at — 132° C., recondensed in a second liquid-air trap and determined separately. The carbon is determined with an accuracy of 0.0002%.

Magnetic Methods for Determining Carbon in Steel. B. A. Rogers, K. Wentzel and J. P. Riott. (American Society for Metals, Oct., 1941, Preprint No. 11). The authors consider whether five magnetic

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properties, namely, saturation, permeability, coercive force, remanence and hysteresis loss could be used as a basis for determining the carbon in steel. They describe their experiments in which the first three of these were applied. The last two were not investigated as they did not appear to offer any advantage over the others. The magnetic saturation and the carbon content could be accurately correlated in the carbon range of from about 0.50% to an undetermined point above 1.10%, but below 0.50% the magnetic-saturation/carbon-content curve had too small a slope to be satisfactory. A new apparatus employing alternating current was used to measure the permeability and the samples used with it required different heat treatments depending on whether the carbon content was above or below 0.40%. A brief description is also given of a simplified apparatus for determining the carbon from measurements of the coercive force.

The Determination of Molybdenum in some Important Alloy Steels. E. Gregory, R. B. Foulston and F. W. Gray. (Analyst, 1941, vol. 66, Nov., pp. 444–448). The authors describe methods of determining molybdenum in alloy steels. The method is based on the precipitation of lead molybdate from formic acid solutions; this, in addition to yielding solutions of considerably higher hydrogen-ion content than when weak acetic acid is used, ensures the reduction of vanadium and chromium salts, so that basic lead vanadates or chromates are not co-precipitated. The procedure to be followed is

given in detail.

The Colorimetric Determination of Large Amounts of Molybdenum in Steel. E. I. Fogel'son and F. S. Kazachkova. (Zavodskaya Laboratoriya, 1940, No. 7, pp. 783–784). (In Russian). The method of determining molybdenum which the authors describe involves solution of the sample in a mixture of sulphuric and phosphoric acids followed by oxidation of the solution with nitric acid and subsequent precipitation of the phosphates of iron and other elements by adding caustic soda. An aliquot portion of the filtrate is acidified and to it is added potassium thiocyanate and it is then reduced with stannous chloride. The colour due to the molybdenum is compared with that obtained using a standard solution of ammonium molybdate. The accuracy of the method is satisfactory for routine purposes. Vanadium and tungsten do not interfere.

Rapid Determination of Vanadium in Steel Without Damage to the Specimen. L. P. Adamovich and A. Ya. Zagorul'ko. (Zavodskaya Laboratoriya, 1940, No. 4, pp. 465–466). (In Russian). In this method of making vanadium determinations the test solution is obtained by placing a few drops of a mixture of sulphuric and nitric acids on a cleaned and degreased portion of the surface of the specimen and transferring the solution obtained after 1–2 min. into a very small crucible. The solution is then boiled with nitric acid, treated with a slight excess of potassium permanganate solution, the excess of the latter being destroyed by adding potassium nitrite, and

a small amount of urea is finally added. A drop of this solution is then placed on filter paper which has been soaked in a solution of aniline hydrochloride and dried. The appearance of a blue spot indicates the presence of vanadium in the specimen. The use of phenyl-anthranilic acid paper gives better sensitivity, but the use of nitric acid when preparing the test solution must then be avoided.

Photo-Electric Method of Determining Vanadium in Steel. A. L. Davydov and Z. M. Vaysberg. (Zavodskaya Laboratoriya, 1940, No. 7, pp. 715-723). (In Russian). A detailed study was made of the conditions under which the formation of the phosphovanadium molybdate and phospho-vanadium tungstate complexes reduced with stannous chloride could be used for the determination of vanadium. A method based on the formation of the latter complex was developed and was found suitable for the determination of vanadium contents of 0.1% to 2% with an accuracy of 4% of the amount being determined. The time taken varied from 18 to 30 min. depending on the time required to dissolve the sample. A light filter with maximum transmissibility at 550 mu is used. 0.1-0.6% of titanium, 0·1-0·6% of copper, 0·03-0·2% of arsenic and 0·1-0·8% of molybdenum do not interfere. 1-5% of cobalt, 0.1-5% of nickel and 1-3% of chromium have practically no effect. In the presence of larger amounts of chromium its effect on the colour of the reduced solution is determined in a blank test.

The Photo-Colorimetric Examination of Alloy Pig Iron and Cast Iron. I. Determining Vanadium. H. Pinsl. (Giesserei, 1940, vol. 27, Nov. 15, pp. 441–446). After a brief discussion of the general application of photo-colorimetric methods of analysis for metallurgical purposes, the author describes an improved technique for making vanadium determinations in pig iron, cast iron and steels soluble in acid. In this method the accuracy of the results are not affected by the presence of titanium, molybdenum or any other

alloying element except tungsten.

Methods for the Photometric Determination of Niobium and Tantalum in Steel, Ferro-Alloys and Slags. G. Thanheiser. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Feb., pp. 371–380). The paper which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 17, pp. 255–265, is

reproduced. (See p. 76 A).

Analysis of Ferro-Niobium. E. I. Gul'dina, T. A. Uspenskaya and Yu. A. Chernikhova. (Zavodskaya Laboratoriya, 1940, No. 5–6, pp. 500–507). (In Russian). A scheme for the determination of niobium and titanium (one sample), and tantalum, tin, aluminium and silicon (separate samples) in ferro-niobium is described. The niobium, tantalum and titanium are determined together; then the titanium is determined colorimetrically and the tantalum from a separate sample by the tannin method, the niobium being obtained by difference. In determining silicon, more reliable results are obtained by evaporating the sample with sulphuric acid and extract-

ing with saturated ammonium-oxalate solution than by the bisul-

phate fusion method.

The Use of Fluorspar in the Analysis of Ferrous Oxide in Acid Open-Hearth Slags. S. V. Budaev. (Zavodskaya Laboratoriya, 1940, No. 7, pp. 792–793). (In Russian). The use of hydrofluoric acid or potassium-ammonium fluoride for the solution of acid openhearth slags which are difficult to dissolve is unpleasant and also results in attack of the glass apparatus. These drawbacks can be avoided by using sulphuric acid to which fluorspar has been added to dissolve the slag. The hydrofluoric acid formed reacts with the silica in the slag to give volatile silicon fluoride, while the finely divided calcium sulphate formed deposits in a thin coating on the walls of the flask and protects the glass against attack. Experiments showed that this procedure had no effect on the accuracy of the analysis.

The Determination of Pyritic Sulphur in Coal. R. Belcher and C. E. Spooner. (Fuel in Science and Practice, 1941, vol. 20, Oct.—Nov., pp. 172–174). The author investigated various methods of determining the pyritic sulphur in coal. The Mantel-Radmacher and other reduction methods were found unreliable. The extraction of a coal with nitric acid by the Parr-Powell method when prolonged to 18 days did not attack the organic sulphur to any appreciable extent. A conventional method is to calculate the pyritic sulphur content from the iron content, and the authors describe a modifica-

tion of the Parr-Powell procedure for determining the iron.

Magnetic Device for Control of the Arc in Spectrochemical Analysis. R. Taylor. (Journal of Scientific Instruments, 1942, vol. 19, Jan., p. 11). The author describes a device used in the course of some experiments on spectro-chemical analysis by an arc method in order to keep the position of the arc more constant than is the case when it wanders freely over the surface of the electrodes.

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MINERAL RESOURCES

(Continued from p. 42 A)

Bentonite in Southern Hawke's Bay. E. O. Macpherson and R. G. Coventry. (New Zealand Journal of Science and Technology, 1941, vol. 22, May, pp. 2658–2758). The authors describe the geology of several bentonite deposits in Southern Hawke's Bay, a poorly exposed deposit near Tinui in East Wellington, and bentonitic beds 20 miles north-east of Porangahau in New Zealand. Estimates of the amount of bentonite available on the surface at the last-named deposits are given.

Iron-Ore Deposits of Venezuela. (Bulletin of the Imperial Institute, 1941, vol. 39, No. 4, pp. 413–416). Some particulars are given of the iron-ore deposits at El Pao in Venezuela which are now being developed by the Bethlehem Steel Corporation. The information is based on reports by Burchard and by Zuloaga and Tello. The outcrops cover an area of 28 acres and the reserves are estimated at 17,000,000 tons. Analyses show an average of 69% of iron with very low phosphorus, sulphur and titanium. There is another deposit of lower-grade ore (45% of iron) in the Sierra de Imataca range, but this is not being worked.

Chromite in the Philippines. W. F. Boericke. (Engineering and Mining Journal, 1941, vol. 142, Nov., pp. 38-40). The author gives an account of the chromite beds and mining operations in the Philippines. This industry has grown very rapidly since 1935, when the amount exported was 1292 tons, as compared with an estimated export of 400,000 tons in 1941. The average analysis of the ore is Cr₂O₃ 33.6%, FeO 14.8%, SiO₂ 3.66% and Al₂O₃

30.16%.

ORES-MINING AND TREATMENT

(Continued from p. 131 A)

The Removal of Arsenic from Oxidic Ores. J. Klärding. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Apr., pp. 473-476). The author reviews the literature on the removal of arsenic from iron ores, and finds that no single satisfactory process which can be applied to any ore has yet been developed. He discusses the chemical reactions and physical behaviour of oxidic iron ores and tin ores which affect the degree to which the arsenic can be removed.

An Investigation into the Wet Concentration of the Vanadium Occurring in the Iron Ores of Mayurbhanj. D. Swarup and V. G. Iver. (Transactions of the Mining, Geological and Metallurgical Institute of India, 1941, vol. 37, Aug., pp. 45-47). The authors describe a laboratory procedure for the extraction of vanadium from the vanadium-bearing titaniferous iron ores from Singhbhum

and Mayurbhanj.

Tests on the Electrolytic Deposition of Manganese from Manganese Chloride Solutions. G. Thanheiser and R. Hubold. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung. 1941, vol. 23, No. 1, pp. 1-19). As a contribution to investigations of methods of recovering pure manganese from ores, the authors carried out extensive laboratory research on the efficiency of electrolytic methods of obtaining manganese from manganese chloride solutions. They found that a pure manganese chloride solution as an electrolyte was unsatisfactory. The effect of additions of ammonium chloride was therefore examined, and the best results were obtained with a high manganese concentration (47–82 g. per litre) and a high ammonium chloride content (160 g. per litre). Electrolytes high in ammonium chloride and low in manganese chloride were also satisfactory, but solutions high in the latter and low in the former were of no use. The stability of the electrolyte increased with increasing ammonium chloride content. Increasing the stirring action raised the rate of deposition. structure of the deposited manganese has an important bearing on the process; the best results are obtained when the deposit is in fine crystalline form.

The Arrangement and Operation of a Pan Sintering Plant, Type GHH-AIB. R. Hahn. (Iron and Steel Institute, 1942, Translation Series, No. 68). An English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, July 3, pp. 654—

658. (See p. 43 A).

REFRACTORY MATERIALS

(Continued from pp. 131 A-133 A)

Canadian Bentonite Clays as Bonding Materials for Synthetic Moulding Sand Mixtures. C. H. Freeman. (Bulletin of the Imperial Institute, 1941, vol. 39, No. 4, pp. 402–406). The author presents a report on five bentonite clays, three from Manitoba, one from Alberta and one from Wyoming, with respect to their suitability as a bond for synthetic moulding sands. The Alberta and Wyoming clays and one of the Manitoba clays were found to have excellent properties. The permeability and compressive strength of fine sand and coarse sand mixtures made up with 3·25%, 4% and 7% of clay are given in tables.

The Use of Missouri Refractories in Blast Furnace Service. C. A. Freeman. (Blast Furnace and Steel Plant, 1941, vol. 29, Nov., pp. 1119–1122). The author discusses the requirements of refractories for lining the hearth, bosh and shaft sections of a blast-furnace, and then presents data on the properties of Missouri clays and refractory bricks, with particular reference to tests in carbon monoxide at about 850° F. Refractories made from Missouri clays are now being used for blast-furnace linings in the United States

after earlier prejudice against them.

Experience with Forsterite Refractories in Steel-Melting Furnaces. A. Berezhnoy and V. Gulyaev. (Stal, 1940, No. 8, pp. 18–27). (In Russian). After surveying previous work on forsterite refractories, the authors briefly refer to the manufacture of forsterite bricks from calcined dunite. 10-15% of caustic magnesite were added, and also 1.7% of magnesium chloride in the case of unfired bricks. Numerous observations on the service given by such bricks in the roofs of electric steel furnaces and (unfired bricks only) in the walls of open-hearth furnaces are reported. In general, forsterite bricks did not prove satisfactory in the former applications, though bricks fired at higher temperatures might well give better results. In open-hearth furnaces, at above the slag level, the bricks were, in general, satisfactory, and in some cases superior to Dinas bricks. Forsterite bricks must not be brought into contact with Dinas or fireclay bricks at temperatures above 1200° C. Two to three courses of chromite or chrome-magnesite bricks may be used between them. A magnesite mortar should be used. Forsterite bricks were found to fail almost entirely because of flaking. Structural changes on heating and diffusion of mainly Fe₂O₃, together with some CaO, Al₂O₃, MnO, &c., into the bricks from the furnace atmosphere and the internal stresses set up as the result are held to be responsible for this flaking. Reducing the porosity and completing structural changes by firing the bricks at a higher temperature is regarded as a means of counteracting the tendency to flake.

Basic Open-Hearth Furnace Bottoms. C. R. Austin. (Industrial Heating, 1941, vol. 8, Oct., pp. 1158-1162). The author describes the development of basic refractory open-hearth bottoms in the United States steel industry. Two types of hearth are now coming into use; one consists of a plastic chrome ore mix above the chrome bricks on the bottom, with a consequent decrease in the thickness of the sintered magnesite hearth; the plastic mixture is applied to a thickness of $2\frac{1}{2}$ -6 in. and it is sintered in situ prior to burning-in the completed hearth. The second type consists of a rammed magnesite mix about 6 in. in thickness. In some cases some of the basic brickwork at the bottom is replaced by this magnesite mix. In a Canadian open-hearth shop there are three furnaces with hearths made entirely of rammed magnesite; one is a 150-ton unit with a hearth 15 in. thick. Eighty tons of the mix were put in in 30 hr. The furnace was brought up to 2900° F. and held until no further seeping of water through to the

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pan was noted. The hearth was then slagged with about 14 tons of slag, half of which was tapped off. The bottom was chilled and allowed to crack; the furnace was brought back to temperature, the cracks sealed with fine magnesite, the bottom dressed with raw dolomite, and the furnace charged. Reference is made to the patent for the Crespi dolomite hearth, but, to the author's knowledge, no furnaces with Crespi hearths have yet been built in the United States.

FUEL

(Continued from pp. 133 A-134 A)

The Radiation of Luminous Flames. Part I. Discussion of the Literature, Working Hypotheses, and Preliminary Experiments. K. Rummel and P.-O. Veh. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Apr., pp. 489-499). Based on the literature for hydrocarbon chemistry, the conditions necessary for, and the possible process of, the formation of luminiferous carbon in luminous flames are investigated and summarised to give a working hypothesis. According to this hypothesis, the luminous carbon particles in the flame are precipitated as residual skeletons of carbon indirectly by way of complex chain reactions, with tar oils as intermediate members. After giving a comprehensive review of the work of the Wärmestelle, Düsseldorf, on the nature of flame, i.e., on the combustion and heat-transfer conditions in industrial furnaces, the results obtained by the author and other workers are quoted. They form the basis of further work on the conversion of hydrocarbon gases, chiefly methane, and the investigation of the connection between the hydrocarbon reaction and the luminosity of flames of gases-containing hydrocarbons. The observations show that, under certain conditions, hydrocarbon-containing gases undergo self-carburisation by being heated prior to their combustion.

The Radiation of Luminous Flames. Part II. New Experiments on Model Flames, Discussion of Results. P.-O. Veh. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, May, pp. 533–542). In the second part of the study of the radiation of luminous flames the author describes measurements made with small models, in which the radiation of flames was measured in cold and in hot furnaces. Ordinary coke-oven gas was used. This work led to the conclusion that when heavy hydrocarbons are burnt with insufficient air, their molecules crack off hydrogen atoms which burn with the oxygen of the air to water vapour by means of chain reactions with a very high heat release. Residual hydrocarbon molecules then form by adhesion in pairs a new larger molecule, which again

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splits off atomic hydrogen. This process is repeated until the hydrocarbon molecules with their abnormally low hydrogen content sublime with increasing concentration at a definite temperature. become incandescent under the heat released by the combustion of the hydrogen, and radiate. These molecule "skeletons" either burn away if the oxygen supply continues, or they cool off and form soot, whilst any unburnt vaporised hydrocarbons condense and give the soot its oily character. The density of the carbon suspension depends on the flame temperature, the furnace temperature and the hydrogen content of all the hydrocarbons present in the gas. Cooled-off soot which reaches the flame reduces its temperature, and thus its heat radiation. The experimental results given can be applied to all fields of gas firing such as annealing and tempering furnaces requiring a soft flame and uniform temperature distribution at high loads, and to high-temperature melting furnaces such as glass and open-hearth furnaces. Self-carburisation of the gas by preheating increases the output; this is achieved by adjusting the gas and air preheat temperatures to the working temperatures and the mixing conditions of the burner. The range of the preheat temperatures lies within narrow limits, but when the mixing conditions of the burner are adjusted to the flame temperature the soot radiation will also increase. The experimental results are also applicable to producer gas provided it contains hydrocarbons.

An English translation of this paper forms No. 59 of the Translation Series of The Iron and Steel Institute.

Analytical Investigations on the Cracking and Conversion of Methane when Heating Fuel Gases Containing Methane. F. Herning. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, June, pp. 581-586). The author describes a laboratory apparatus which enabled data to be obtained on the composition of the gases formed by heating industrial fuel gases containing methane, and discusses the results obtained. The object was to establish the optimum heating conditions for converting the methane into hydrocarbons such as tar, naphthaline and light oils. From the information obtained it was concluded that it would be quite possible to apply self-carburising fuel gases containing cracked methane for the heating of open-hearth furnaces. The most suitable method of cracking the methane would be by preheating it in the regenerator

Construction of Bunkers, Silos, and Coal-Towers from the Point of View of the Hanging of the Coal. V. G. Zashkvara. (Koks i Khimiya, 1940, No. 9, pp. 16-25). (In Russian). The behaviour of coal in bunkers, silos and coal-towers is considered partly on the basis of theory and small-scale experiments, but mainly on the basis of practical plant experience. The latter provides evidence that the hanging of coal can be considerably reduced by using conical instead of pyramid-shaped bottoms and having the opening eccentrically positioned. Interior inclined surfaces should be

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smooth (preferably lined with sheet iron), and there should be a gradual transition between the vertical and inclined surfaces. The effects of certain characteristics of the coal on its tendency to hang are also considered. In the case of towers, in addition to the above features, the bottoms should be made of metal, openings should be made as large as possible, some provision should be made for the breaking up and distribution of the flow of the coal being charged, and "breakers" should be provided near the openings to counteract compacting of the coal on the inclined surfaces and to prevent bridging.

Carbonisation by Electricity. (Coke and Smokeless-Fuel Age, 1942, vol. 4, Jan., pp. 9–10, 18). The history of carbonising coal by electricity is reviewed, and a description is given of a retort built in 1937 by the Tennessee Valley Authority. The retort has a steel shell 24 ft. high and 4 ft. in dia. It is lined with insulating brick between the steel and the refractory facing of carbon brick, the latter acting as one electrode, the other being a 10-in.-dia. graphite rod. The operating results achieved with this retort are:

Throughput 2,400 lb. per hr. Gas make 18,300 cu. ft. per ton Calorific value . 461 B.Th.U. per cu. ft. Power consumption . 485 kWh. per ton Gas yield 5.09 B.Th.U. per B.Th.U. of power Tar yield gal. per ton Coke yield lb. per ton 1,345

The possible application of the process in Great Britain and on the Continent is discussed.

Determination of the Temperature Distribution in the Dinas Partition-Wall of a Coke Oven. M. D. Tamarin. (Koks i Khimiya, 1940, No. 9, pp. 29–33). (In Russian). An approximate heatflow method of calculation is used to determine temperatures both in the partition-wall and in the coke charge at different distances from the heated side and various times after charging. The bearing of the rates of heating and cooling on the life of the Dinas refractory wall is considered.

The Thermal Resistance of Metallurgical Coke. A. D. Zaslavskaya. (Koks i Khimiya, 1940, No. 10, pp. 26–29). (In Russian). In the experiments reported, specimens of coke were heated in a coke-fired stove for $2\frac{1}{2}$ –3 hr. and then cooled by spraying with water. In the first series of tests the effect of such heating on the surface fissuring of specimens with different amounts of original fissuring was investigated. Coke with a small amount of original fissuring increased this by developing new fissures, whilst coke with a large amount of original fissuring only exhibited a change in the nature of the fissuring, the number of fissures decreasing while the long and deep fissures increased in size. Dropping and compression tests on hot coke showed that it was less strong, the number of pieces formed in the dropping test being $1\frac{1}{2}$ –2 times

that formed in the cold state. Fissuring lowers the resistance of coke to the effect of high temperatures.

PRODUCTION OF IRON

(Continued from pp. 134 A-136 A)

Six Months Operating Experience with Modern Air-Conditioning Equipment on a Large Blast Furnace. E. K. Miller. (Eastern States and Chicago District Blast Furnace and Coke-Oven Association: Blast Furnace and Steel Plant, 1941, vol. 29, Nov., pp. 1103-The author presents and discusses data relating to the results obtained after the installation of a dehumidifying plant at a blast-furnace of the Jones & Laughlin Steel Corporation. This furnace has a hearth diameter of 28 ft. 6 in., a stack height of 90 ft. and 18 tuyeres, and it produces about 1000 tons per day. The figures given cover the period June to September, 1941, in which the air-conditioning plant reduced the moisture in the blast from an average of about 6 grains per cu. ft. to about 3.5 grains. In these months an average increase of 16% in the production of iron was obtained with a decrease of 4.26% in the coke consumption. The increase in production over a period of twelve months is expected to be not less than 8%. The turbo-blowers also required less steam for blowing the conditioned air, and this saving alone more than covered the operating cost of the conditioning plant.

The Control of the Working of a Blast Furnace in Practice. B. Zherebin. (Stal, 1940, No. 8, pp. 7-10). (In Russian). In a general discussion the author considers the effects of blast volume, pressure and temperature on the working of a blast furnace. Conditions under which blast pressure must be raised or lowered are summarised. The proper blast temperature is determined mainly by the physical characteristics of the burden; factors necessitating temperature changes are considered. Causes of scaffolding are described, and methods of eliminating these are suggested. The author also deals with the sequence adopted for the charging of coke and ore at the Kuznetskiy works under normal working conditions, and also the sequences used to obtain different distributions of the constituents with the object of curing abnormal conditions in the furnace. In conclusion, the method of adjusting composition of the charge on the basis of blast-furnace dust elimination

is dealt with.

Desulphurisation with Acid Slags. R. Durrer, H. Hellbrügge and B. Marinček. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, May, pp. 527-532). The authors report on an investigation of the possibilities of desulphurising molten iron with acid slags, how the process was affected by the slag composition and temperature

and the nature of the silicon-sulphur compound which is formed. The laboratory experiments proved that molten pig iron could be almost fully desulphurised provided the temperature was high enough (about 1700° C.) and that the sulphur left the melt in the form of gaseous silicon monosulphide and did not pass into the slag which remained low in sulphur. It was the silica in the slag, rather than the silicon in the iron, which was the sulphur carrier in the gas phase.

Science of Slags as a Basis of Ferrous Metallurgy. F. Körber and W. Oelsen. (Iron and Steel Institute, 1942, Translation Series No. 74). An English translation of a paper which appeared in Stahl und Eisen, 1940, Oct. 17, pp. 921–929; Oct. 24, pp. 948–

955. (See p. 7 A).

FOUNDRY PRACTICE

(Continued from pp. 136 A-137 A)

Air-Weight Control for Foundry Cupolas. J. R. Howard. (Industrial Heating, 1941, vol. 8, Oct., pp. 1098–1104). After stressing the importance of controlling the amount of oxygen in the blast supplied to a cupola, the author describes an automatic controlling system for this purpose. The controller meters the air in the blast-line, and has a compensator which is actuated by fluctuations in the atmospheric pressure and temperature; this in turn operates a valve which admits more or less air to the cupola

so as to keep the amount of oxygen constant.

Two New Types of Furnace for Electric-Furnace Grey Iron. H. Beissner. (Giesserei, 1941, vol. 28, June 13, pp. 265-268). After discussing the applications, advantages and disadvantages of the cupola, arc furnace and high- and low-frequency furnaces for producing high-quality grey cast iron, the author describes two recent improvements in design, one for low-frequency and the other for high-frequency furnaces. A disadvantage of low-frequency furnaces was the high temperature difference between that of the iron in the submerged channel and that of the metal in the bath which was so very much larger, this limited the current which could be fed to the furnace and necessitated frequent relining of the channel. In the improved furnace the channel is made very much wider so that a 3-ton furnace can be fed at 700-800 kW., and the whole charge can be superheated by 200° C. in less than 30 min., or 3 tons of cold metal charged into molten metal in the bottom can be melted down in under 2 hr. In the improved furnace the lining of the channel is expected to last for 1000 melts. The improvement to the high-frequency furnace consists in designing it with a tap-hole instead of making it tilting. This not only

eliminates the tipping mechanism, but also the magnetic screening which was necessary for it. It cheapens the foundation, saves the cost of frequently relining the spout and lowers the current con-

sumption of the furnace by about 10%.

Pattern-Making and Pattern Design. R. R. Shaw. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 66, Jan. 29, pp. 71–72). The author points out the disadvantages of four common methods of making patterns and moulds for rainwater gutters, and explains a new technique which eliminates the difficulties described.

The Application of Feeder Heads in Grey Iron Castings. F. Naumann. (Giesserei, 1941, vol. 28, June 13, pp. 268–271). The author discusses the principles governing the design of feeder heads for grey iron castings, especially the relation of height to section and to the mass of the casting. He also describes the pattern-

making and moulding technique for feeder heads.

The Economical Use of Moulding Machines for Semi-Mass Production. H. H. Jones. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 66, Jan. 29, pp. 73–74). The author considers the factors affecting the selection of one of the following types of moulding machines to increase the production in a jobbing foundry in South Africa: (a) Plain jolt; (b) plain squeezer; (c) jolt squeezer; (d) jolt stripper; (e) jolt squeeze stripper; (f) jolt rollover pattern draw; and (g) jolt roll-over squeeze pattern draw.

The Production of Composite Castings by the Consecutive Pouring of Melts of Two Metals. P. Je. Ljamin. (Litejnoje Djelo: Giesserei, 1941, vol. 28, June 13, p. 273). A brief account is given of some casting experiments carried out in the U.S.S.R. A small revolving mould 95 mm. in dia. × 87 mm. deep was used at a peripheral speed of 8 m. per sec., and the following combinations of metals were cast in it: (1) Steel with an inner layer of bronze; (2) bronze followed by steel; (3) cast iron and bronze; (4) bronze and cast iron; and (5) aluminium (86% pure) with an inner layer of an aluminium-base bearing metal. In each case tests were made at different time intervals between the pouring of the first and second metals, in order to ascertain the conditions which gave the best adhesion between them. For the above combinations the optimum time intervals were 20 sec., 30-40 sec., 15-25 sec., 20 sec. and 15-25 sec. respectively. The preparation of the mould and the pouring temperatures are stated, but no details of the quantities cast are given.

Bucket Elevators for Foundries. H. Schulze-Manitius. (Giesserei, 1941, vol. 28, June 27, pp. 290–294). The author describes and illustrates different types of bucket elevators suitable for moving moulding sand and coke in foundries. The lubrication and

maintenance are also discussed.

The Activities of the Verein deutscher Giessereifachleute in the Year 1940. (Giesserei, 1941, vol. 28, May 30, pp. 241–252). A

review is presented of the work of the Verein deutscher Giesserei-fachleute during 1940. It is divided into reports on the activities of the technical committees on grey iron, steel castings, malleable iron castings, non-ferrous castings, pressure casting, hardness, heat and standard specifications.

PRODUCTION OF STEEL

(Continued from pp. 137 A-138 A)

Metal Handling with Magnets in Steel Plants. A. E. Lillquist. (Steel, 1941, vol. 109, Dec. 22, pp. 58-64). The author discusses the increasing use of lifting magnets for moving pig iron, billets, flat and coiled sheets, bars and scrap in steelworks, and gives details of some large circular, rectangular and bipolar magnets

and their particular applications.

Influence of the Composition of Bessemer Iron on the Quality of Rail Steel. M. Kravets and N. Stupar. (Stal, 1940, No. 8, pp. 15–17). (In Russian). High manganese contents (above 0.9%) in the iron were found to have a detrimental effect on the quality of the Bessemer steel rails produced from the iron; it increased the proportion of rejects due to tears and skin defects. This influence of manganese is ascribed to certain effects it has on the behaviour of the iron in the converter. This, and possibly also the increased absorption of nitrogen, also explain why manganese increases the brittleness of the steel. High manganese contents are particularly undesirable when associated with high silicon contents. The optimum manganese content of the iron is 0.50–0.70%. The influence of silicon in increasing the brittleness of the steel was not definitely confirmed.

Investigation of the Heat Supply to the No. 9 Open-Hearth Furnace at the Kuznetskiy Works. D. Savostin. (Stal, 1940, No. 8, pp. 11-15). (In Russian). In connection with the experimental automatic thermal control of the open-hearth furnaces at the Kuznetskiy and Magnitogorsk works, the author has investigated the relation between fuel and air consumption, the influence of the rate of heat supply on the duration of the different periods of the open-hearth process and actual heat requirements of each period. Analysis of the products of combustion from the flue showed that their optimum oxygen content for complete combustion was 2%; their temperature should be 450-500° C. From this it was found that the optimum proportion of air to fuel (mixture of coke-oven and blast-furnace gases) varied for the different periods of the process. To obtain an oxygen content of 2% in the products of combustion a 1·3 excess of air must be used during the charging and heating-up periods, and a 1.45 excess during the

melting and finishing periods. Working on this basis, a reduction of 16% in the heat consumption to 1084 cal. per kg. of steel was achieved. Nomograms for making the calculations are given. With the exception of charging, the duration of the periods of the process was found to be dependent on the rate of heat supply, and, in the case of the finishing period, an optimum rate of 18–19 million cal. per hr. was definitely established. For the best results, the rate of charging should be related to the rate of heat supply at the time. In conclusion the optimum calorific value (proportions of coke-oven and blast-furnace gas) of the fuel in relation to the optimum rates of heat supply during the different periods of the process are considered.

The Manufacture of High-Quality, Low Cost Steel. P. J. McKimm. (Steel, 1941, vol. 109, Dec. 15, pp. 62-70). Continuation of a series of articles (see p. 51 A). The author describes the development of an open-hearth practice for producing deep-drawing quality steel. This practice included having 40-45% of pig iron in the charge, decreasing the limestone, eliminating spiegel additions and using

iron higher in manganese.

Rapid Training in Spoon Testing for Tapping Temperatures. A. G. Arend. (British Steelmaker, 1942, vol. 8, Feb., pp. 28–29). The author discusses the use of projected ciné films for the training of steel-furnace operatives in making temperature determinations from spoon samples of molten steel. The principal advantages of this method of training are the great saving in the time required for training and the ease with which correct and incorrect procedure can be demonstrated.

Arc Furnace Electrode Holders. (Iron and Steel, 1942, vol. 15, Jan., p. 142). After a brief discussion of the disadvantages of cast steel as a material for holding the electrodes of electric steel furnaces, some information is given on the advantages of a new precipitation-hardened copper alloy containing chromium and silicon for this purpose. The material in the cast form has an electrical conductivity of 80% of that of standard copper, a tensile strength of

22 tons per sq. in. and a Brinell hardness of 120.

The Behaviour of Fluorspar and of Calcium Phosphates in Relation to the Ferrous Oxide in the Melt and Its Metallurgical Significance. W. Oelsen and H. Maetz. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 12, pp. 195–245). In steel production the action of fluorspar in lowering the viscosity of slags even at moderate temperatures and its effect on the lime are well known, but its influence on the other basic ingredients of slag, such as iron oxides, manganous oxide, silica and phosphates, has not been the subject of much investigation. The authors therefore undertook a thorough investigation of the whole subject. Having established that, in the molten state, ferrous oxide and fluorspar are practically immiscible, and that the melting point of each is not appreciably lowered by the presence of the other,

the authors determined the distribution in slags having a lower layer rich in ferrous oxide and an upper layer rich in fluorspar, of lime, manganous oxide, silica, phosphorus pentoxide, iron sulphide, calcium orthosilicate and calcium metasilicate. The slags were melted in iron crucibles at 1400-1450° C. The investigation of the FeO-CaO-P₂O₅ system led to the surprising conclusion that there is a lens-shaped immiscibility area of two layers which, with a P_2O_5 content of under 40%, extends from the ferrous-oxide corner across the isothermal ternary diagram towards the point of calcium orthophosphate concentration, and that this has two critical points, one near the FeO-P2O5 side at about 15% P₂O₅ and 1-2% CaO. Its position points to the fact that ferrousoxide/iron-phosphate slags have a definite tendency to separate; this view is also supported by the form of the curve of primary crystallisation of these slags between 0 and 25% P₂O₅. The addition of only a little lime causes the separation of these iron-phosphate slags into two layers. The tie-lines are determined by the ratio $(\rm mol)CaO/(\rm mol)P_2O_5<3$; their direction indicates that the section FeO-3CaO.P_2O_5 is a quasi-binary one. The solidification diagram for this section is developed, and it emphasises the very low solubility of solid tricalcium phosphate in molten ferrous oxide as well as the breadth of the immiscibility gap in the molten state. The crystalline tetraphosphate 4CaO.P,O, is much less stable than the orthophosphate.

As ferrous oxide and tricalcium phosphate, as well as ferrous oxide and fluorspar, in the molten state are thus seen to be only slightly miscible, whilst tricalcium phosphate and fluorspar are miscible, the system FeO-CaF₂-3CaO.P₂O₅ will consist of two layers at almost all concentrations. Of these, the lower consists of almost pure ferrous oxide with small quantities of phosphorus pentoxide, calcium and fluorine, and the upper one of tricalcium phosphate and fluorspar with only a little ferrous oxide. The ratio of the P₂O₅ contents of the upper and lower layers is about 128, and that of the iron in the lower and upper layers is about 42, at about 1400° C. in both cases. The separation of the two layers is also applicable to the system FeO–CaO–P $_2$ O $_5$ –CaF $_2$ when the (mol)CaO/ (mol)P₂O₅ ratio is greater or less than 3. When this ratio is 3, special conditions obtain. When the ratio is less than 3, the upper layer still contains considerable amounts of ferrous oxideof course mainly dissolved as iron phosphate—whilst with a ratio greater than 3, there is very little ferrous oxide in the upper

layer.

The distribution of the manganous oxide in the two layers for different ${\rm CaO/P_2O_5}$ ratios was studied. As long as (mol)CaO/(mol)P₂O₅ < 3 most of the manganous oxide goes into the upper layer as manganese phosphate, but as the value of this ratio increases, more and more manganous and ferrous oxides pass into the lower layer. The changes in this distribution under different conditions

are followed and explained. The relation between these laboratory investigations and the structure of basic-Bessemer slags obtained in full-scale operations, as well as their significance in magnetic methods of recovering iron and preparing manganese-rich concentrates, are discussed at length. In conclusion a new technique is suggested for the separation of phosphorus from both iron and manganese; this comprises the melting of phosphoric ores, such as Kiruna ore, with or without additions of fluorspar or other fluxes containing fluorine or chlorine, and drawing off the upper phosphaterich slag layer from the lower layer, which is rich in ferrous oxide and low in phosphorus pentoxide.

Material for Steelworks' Ingot Moulds. K. Hoffmann. (Iron and Steel Institute, 1942, Translation Series, No. 71). An English translation of a paper which appeared in Stahl und Eisen, 1941,

vol. 61, June 19, pp. 606-609. (See p. 54 A).

FORGING, STAMPING AND DRAWING

(Continued from pp. 139 A-140 A)

Forging 155-mm. Shell Bodies. F. G. Schranz. (Machinist, 1942, vol. 85, Feb. 7, Armament Section). A detailed and illustrated description is given of the forging of 155-mm. shells. The raw material consists of 0.40% carbon steel in billets $6\frac{1}{2} \times 6\frac{1}{2}$ in. \times 20 ft. long. These are cut into 24\frac{3}{4}-in. lengths in an oxyacetylene cutting machine fitted with a second burner which simultaneously nicks the cut lengths at the centre. These then pass to a hydraulic press, which breaks them at the nick. The next operation is that of heating in a reverberatory oil-fired furnace to 2150° F. The heated blanks are then descaled by jets of water at high pressure, and pass to a Baldwin-Omes piercing machine. In this machine the blank is held in a split die and pierced with a mandrel moving at about 14 in. per sec., the capacity of the machine being 50-60

New Shell Forging Plant Very Efficient in Operation. W. N. binson. (Heat Treating and Forging, 1941, vol. 27, Nov., pp. 551-556, 564). The author describes and illustrates a shellforging plant at an American automobile works where 75-mm. shells are made from 2\frac{3}{8}-in.-dia. bars and 105-mm. shells from 3-in-dia. bars. The blanks are heated by eight sets of induction-heating equipment, five for the smaller size and three for the larger. It takes only 2 min. 20 sec. to heat the smaller blank to 2275° F. There are eight horizontal forging machines, which produce the hollow shell forging in six stages, after which no machining of the cavity is required. The forgings are next cleaned by shot-blasting, and then pass to the machine shop for finishing.

The Determination of Production Time in Drop Forging Plants. P. Patek. (Heat Treating and Forging, 1941, vol. 27, Nov., pp. 559–560, 569–571). The author presents formulæ for calculating the time required to produce drop forgings, and gives some examples

of their application.

Heat Transfer and Heat Loss in Forging and Pressing. and A. Pomp. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 8, pp. 105-120). The authors describe an investigation of the effect of different forging and pressing conditions on the rate of cooling of the work while in contact with the hammer, or the die and the pressing head. This was done by drilling a test-plate to take a thermocouple in the centre plane and plotting time-temperature curves for the cooling of the plate as it was pressed between cold dies and dies preheated up to 420° C. The effects of die pressure, scale, initial temperature of plate and dies, and of the die material, shape and mass were studied. Apart from the temperature difference between the plate and dies, the amount of scale was the only factor of practical importance with regard to the rate of cooling. The cooling characteristic calculated from the initial temperature decrease between plate and dies is not dependent on the actual temperatures of the plate and dies and the quantitative value of the temperature difference. A comparison between the observed and the calculated cooling characteristics showed that the rate of heat transfer apparently decreases as the cooling proceeds, probably because the die surfaces become heated. Calorimetric determinations were therefore made of the heat loss of specimens from 4 to 120 mm, thick when in contact with the dies for extended periods. Curves were plotted from the data obtained, and these enable the rate of heat transfer of flat steel plates to be determined under any conditions of pressing practice, given the physical properties of the steel, its thickness and the time it is in contact with the dies.

Tests with specimens varying in diameter and thickness showed that their rates of heat transfer could also be accurately determined from the curves by obtaining the mean thickness. Finally it was established that the rates of heat transfer between solid metal surfaces with no scale is very high, and that it does not alter as

the cooling proceeds.

The Rate of Heat Transfer of Solid Metal Bodies in Contact. W. Lueg. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 8, pp. 121–122). The author describes some experiments to test the validity of the theory that the rate of heat transfer between two solid metal bodies in contact is a constant, and that any apparent change is due to the increase in temperature of the colder body (see preceding abstract). A testplate of heat-resisting steel with a thermocouple in a hole in the centre plane was put in a forging press, the head and die of which were water-cooled. Cooling curves from 710° C. to room tempera-

ture were obtained using dies of plain carbon steel and of copper with and without water-cooling. A comparison of these curves with the theoretical curve proved that the rate of heat transfer

does remain constant as the cooling proceeds.

How Metallurgy Affects Deep-Drawing. K. D. Moslander. (Machine Design, 1942, vol. 14, Jan., pp. 60–65, 128–130). The author discusses how grain size and orientation and the work-hardening properties of metals and alloys affect their deep-drawing properties. Work hardening is a property without which a metal could not be drawn, for, as a metal "necks down" in drawing, the stress at the elastic limit of the reduced portion must increase, in order to transmit sufficient stress to strain the unreduced metal. If the stress does not increase sufficiently, necking down will be followed directly by failure.

Deep Drawing May Answer Your Production Problems. K. D. Moslander. (Machine Design, 1941, vol. 13, Dec., pp. 64–68, 138–142). The author discusses factors in deep-drawing operations which limit the dimensional tolerances within which parts can be made by this process and which affect the cost of production.

Carbide Die Service Boosts Mill Tonnage. A. E. Glen. (Wire and Wire Products, 1941, vol. 16, Dec., pp. 743–746, 770, 771). The author describes the organisation and equipment of a carbide

die service shop for a wire works.

The Heating-Up of Wire and Die in Cold-Drawing. A. Eichinger and W. Lueg. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 2, pp. 21–30). The authors describe the apparatus they developed for measuring the rise in temperature of both wire and die and the power consumed when drawing steel wire. From the data obtained the coefficient of friction was calculated. In the case of a soft steel wire the consumption of mechanical energy corresponded to the increase in heat, but in the case of a 0.6% carbon steel wire in the patented and annealed state a residual latent heat of about 10% was established.

ROLLING-MILL PRACTICE

(Continued from pp. 140 A-141 A)

Motor Bearing Changeovers. A. A. Van Pelt. (Iron and Steel Engineer, 1941, vol. 18, Dec., pp. 26–35). The author discusses the design of roller and ball bearings suitable for replacing plain bearings in old electric motors for rolling mills, cranes and general purposes in steelworks.

Application of Anti-Friction Bearings in Mill Auxiliaries. S. M. Weckstein. (Iron and Steel Engineer, 1941, vol. 18, Dec., pp. 36–39). The author discusses the design of taper roller bearings for

rolling-mill screwdowns, vertical edging rolls, manipulators, turn-

tables and mill-stand guides.

Application and Maintenance of Steel Mill-Table Bearings. H. E. McGoff. (Iron and Steel Engineer, 1941, vol. 18, Dec., pp. 46–48). The author discusses the development of bearings for steel mill tables, in particular two designs of roller bearings which

have given very satisfactory service.

The Occurrence of Folding Cracks when Rolling Steel with Unrestricted Lateral Spread. A. Pomp and W. Lueg. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, June, pp. 589–599). The authors' report on their investigation of the rolling conditions which promote the formation of folding cracks when rolling flat steel bars is reproduced. This was published previously in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940,

vol. 22, No. 16, pp. 241-249. (See p. 64 A).

A Modern Universal Steel Rolling Mill. E. Lebed and B. Rogoznyy. (Stal, 1940, No. 8, pp. 28–37). (In Russian). A detailed illustrated account is given of a modern two-high reversible universal rolling mill with ancillary equipment and its operation at the Dzerzhinskiy works since February, 1936. The mill was planned for an output of 140,000 tons of steel plate 300–1050 mm. wide, 6–50 mm. thick and up to 36 m. long, produced from slabs weighing from 500 to 4,700 kg. In addition, certain defects in the mill, such as incorrect roll camber, insufficient provision for roll cooling and weakness of the mechanism for adjusting the vertical rolls which had to be rectified are described. Textolite bearings were substituted for the original bronze bearings with an increase in life from a maximum of five days to up to six weeks. The output of the mill reached 171,052 tons in 1938, and an output of 300,000 tons has been planned.

Low-Carbon Sheets and Strip. M. B. Sunderland. (Canadian Metals and Metallurgical Industries, 1941, vol. 4, Nov., pp. 292–295). The author reviews progress in the manufacture of low-

carbon steel sheet and strip.

HEAT TREATMENT

(Continued from pp. 141 A-148 A)

Modern New Heat Treat at Wright Aeronautical Speeds Production of Aircraft Engines. H. C. Yeager and H. E. Linsley. (Industrial Heating, 1941, vol. 8, Oct., pp. 1085–1092, 1106–1110). An illustrated description is given of the recently completed heat-treatment department at the aircraft engine works of the Wright Aeronautical Corporation. The plant includes radiant tube, con-

trolled atmosphere, pusher furnaces; vertical cylindrical carburising furnaces; salt-bath furnaces; electric nitriding furnaces; and

automatic quenching equipment.

Heat-Treatment of Molybdenum High-Speed Steels. (Machinery, 1942, vol. 60, Jan. 29, pp. 33–35; Feb. 5, pp. 57–58). Detailed information is presented on the heat treatment of molybdenum high-speed steels containing up to 9.50% of molybdenum and not more than 6% of tungsten, and some recommendations are made on the selection of controlled-atmosphere and immersed-electrode salt-bath furnaces for this purpose.

Molybdenum High Speed Steels. H. J. Stagg. (American Society for Metals: Canadian Metals and Metallurgical Industries, 1941, vol. 4, Nov., pp. 296–297). The author discusses the heat treatment to be applied to three types of molybdenum high-speed steels which are now being used as substitutes for the steel containing 18% of tungsten. He refers to these as the Emmons, Kingsbury

and Brealy types, and their analyses are as follows:

			Emmons.	Kingsbury.	Brealy.
Carbon % .			0.85	0.85	0.83
Tungsten %			1.50	***	5.50
Chromium %		٠	3.75	4.00	4.00
Molybdenum %			8.75	8.00	4.00
Vanadium %			1.10	$2 \cdot 25$	1.50

The Heat Treatment of High Speed Steel. H. W. Pinder. (Machine Shop Magazine, 1942, vol. 3, Feb., pp. 110–116). The author describes the procedure for heat-treating high-speed steels of the 18/4/1 (tungsten, chromium, vanadium) type on the black-

smith's hearth and in gas, electric and salt-bath furnaces.

Surface Hardening of Stainless Steels. E. G. Hoch jun. (Industrial Heating, 1941, vol. 8, Oct., pp. 1149–1156, 1172). The author describes the equipment required for nitriding stainless steel. The process is carried out with dissociated ammonia in a muffle furnace at about 1050° F. In chromium steels with no nickel it is possible to obtain a case up to 0.020 in. deep with a Brinell hardness of 850. The corrosion resistance of the hardened surface is slightly reduced by the process, and the results of some corrosion

tests before and after hardening are given.

The Application of Results of Equilibrium Investigations to Furnace Atmospheres and Problems of Bright Annealing and Annealing without Decarburisation. Part B. Development of the Total-Carbon Curves for the Gaseous State. Part C. Further Examination of the Equilibria within the Gas Phase and between the Gaseous and Solid Phases. G. Neumann. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Apr., pp. 479–488). The author continues his study of equilibrium conditions of annealing furnace atmospheres (see p. 58 A) by developing in Parts B. and C. of the report total-carbon curves and water-gas equilibrium curves for these atmospheres at different temperatures.

Carbon Pressure Control of Furnace Atmospheres. J. R. Gier. (Steel, 1941, vol. 109, Dec. 22, pp. 54–56). The author describes the principles, construction and operation of an instrument for measuring the carbon pressure of an atmosphere used for heattreating steel. This is the hot-wire gas analyser. It consists of a thin steel wire in a glass tube, through which is passed the gas to be tested. The wire is heated by an electric current to 1800° F. The steel wire absorbs carbon from the gas until a state of equilibrium is reached which takes 5–10 min. The current is then cut off and the wire is drawn out of the tube. The carburised portion is held between electrical contacts so that it forms part of a bridge circuit. Its resistivity is measured, and is a function of the amount of carbon absorbed.

The Loss of Strength with Time due to Annealing of Cold-Rolled Steel Strip for Deep-Drawing Operations. A. Pomp and G. Niebch. (Iron and Steel Institute, 1942, Translation Series No. 65). An English translation of a paper which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 8, pp. 109–119. (See Journ. I. and S.I., 1941,

No. II., p. 206 A).

The Bright Annealing of Cold-Drawn Deep-Drawing Steel Strip in the Continuous Annealing Furnace. A. Pomp and G. Niebch. (Iron and Steel Institute, 1942, Translation Series No. 66). An English translation of a paper which appeared in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 8, pp. 121-136. (See Journ. I. and S.I., 1941, No. II., p. 205 A).

Cooling Velocities and Coefficients of Thermal Conductivity when Patenting Steel Wire in Different Cooling Agents. W. Lueg and A. Pomp. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 4, pp. 41–51). The authors report on an investigation to determine whether molten salt baths could be used instead of lead for patenting steel wire. The paper has also appeared in Stahl und Eisen, 1941, vol. 61, Mar., pp. 266–270. (See Journ. I. and S.I., 1941, No. II., p. 11 A).

Controlled Oil Quenching. (Wild-Barfield Heat-Treatment Journal, 1941, vol. 4, Sept.-Dec., pp. 56-58). In this article the advantages of controlling the temperature of the oil used for quenching are pointed out and a description is given of an efficient cooler for the purpose. (See Journ. I. and S.I., 1941, No. II.,

p. 208 A).

WELDING AND CUTTING

(Continued from pp. 148 A-149 A)

Unusual Fracture Phenomena in the Weld Metal of High-Quality Electric-Arc Welds. H. Bennek and F. H. Müller. (Archiv für

das Eisenhüttenwesen, 1941, vol. 14, June, pp. 605-614). The authors examine the conditions of welding which promote the formation of "fish-eye" fractures in weld metal. These shallow circular areas of a much lighter shade than the surrounding metal have been described in the American literature (see Journ. I. and S.I., 1941, No. I., p. 25 A). The present authors also report on a detailed investigation of the possible causes, and come to the conclusion that the fish-eye phenomenon is due to hydrogen in the weld metal which originates mainly from the electrode coating and partly from the electrode wire. When fish-eyes are suspected in a weld the danger of brittle fracture can be removed by suitable

annealing treatment.

The Handling of Ni-Clad Steel. J. V. Kielb. (Welding Journal, 1941, vol. 20, Nov., pp. 784-786). The author describes the technique for the welding of nickel-clad steel plate, i.e., steel plate with a nickel coating of a thickness equal to about 20% of the total thickness. In preparing the joint edges, a very successful method is to use a pneumatic chisel to cut a U-groove in the nickel and then to cut the V-groove in the steel from the other side with the machine or hand oxy-acetylene torch. In the welding it is best to weld up the V-groove in the steel first, using small electrodes of say 1-in. dia. for the first three beads; this reduces the heat input and the migration of the nickel into the steel. Before commencing to weld the nickel side, the lower side of the first bead of the mild steel is chipped out from the nickel side to a depth of about \(\frac{3}{16}\) in. and the weld metal is inspected for cracks; any cracks are chipped out and the groove is welded up using nickel-steel electrodes $\frac{5}{32}$ in. in dia.

Arc Welding of Cast Iron. (Welding Industry, 1942, vol. 9, Jan., pp. 292–294; Feb., pp. 12–14). A review is presented of the characteristics of plain and alloy east irons with special reference to those affecting its welding properties, and practical suggestions are made to assist welders in obtaining sound welds when

working on cast iron.

The Gas Welding of Cast Iron. T. Brownlie. (Welding Industry, 1942, vol. 9, Feb., pp. 23-24). The preparation of cracked cast iron parts for welding, the preheating, welding technique and pre-

cautions to be taken in cooling are explained and described.

Oxyacetylene Pressure Welding of Railroad Rails. L. Adams. (Welding Journal, 1941, vol. 20, Nov., pp. 769–775). The author describes the Oxweld automatic process of pressure butt-welding rails. This consists of bringing the properly prepared ends of two rails in a suitable sturdy machine, clamping them in accurate alignment, compressing the ends together with continuously applied hydraulic pressure, while a series of oxy-acetylene flames are applied all round the railends at the point of juncture. This heat is applied continuously until the metal of the rails reaches the plastic state. The joint is not a fusion weld, but a weld in which the

action takes place while the metal is, metallurgically speaking, in the solid state. A portion of the excess metal at the weld, which has become upset, is then removed, and the weld zone is reheated to above the critical temperature and allowed to cool in a normalis-

ing operation which refines the grain.

Details are given of the preparation of the rail-ends, the equipment, the welding procedure, the trimming, normalising and grinding of the welds, as well as some results of tests on welds. The actual welding cycle for a 112 lb.-per-yard rail takes 8 min., but when the time for moving rails in and out of the machine and setting up is included, an average of three welds per hour can be made.

Joining Brass to Steel. J. S. Graham jun. (Welding Journal, 1941, vol. 20, Nov., p. 783). The author describes the procedure for welding brass spoons and points on the ends of steel bars to make mining tools which are used for cleaning out drill holes. Before welding, the end of the brass tool is ground to a chisel shape and this is put against the end of the steel bar which is left square. Standard bronze-welding technique with a slightly oxidising flame is followed. The cost of bronze welding is only a small fraction

of the cost of a machined and fitted joint.

Unusual Steel Assemblies Brazed in Continuous Roller Hearth Furnaces. W. F. Ross. (Heat Treating and Forging, 1941, vol. 27, Nov., pp. 573-576, 581). The author describes and illustrates an electrically heated roller-hearth furnace nearly 60 feet long which is used for brazing steel parts. The furnace is divided into four zones; the first is a long zone for bringing the parts gradually up to a temperature of just under 2040° F.; this is followed by two short zones in which the parts are rapidly heated to 2040° F. The fourth zone is a long, rectangular cooling chamber. The furnace is supplied with a non-oxidising protective atmosphere. A novel method is used to force together the surfaces to be brazed in the case of hollow bodies such as evaporators for refrigerators. two halves are clamped together with a copper template in between, and all holes in the hollow body are stopped up except one. the part reaches the final heating zone, the operator stops the conveyor and passes a tube through a gas-tight swivel joint in the side of the furnace; this tube is made to fit the remaining hole in the hollow body; the other end of the tube is connected to a vacuum pump. Applying suction to the vessel adds to the pressure on the joint.

CLEANING AND PICKLING OF METALS

(Continued from pp. 100 A-101 A)

Electropolishing Stainless Steel. C. L. Faust and H. A. Pray. (American Electroplaters' Society: Steel, 1941, vol. 109, Nov. 17,

pp. 80, 82, 101, 102). The authors give the compositions of three sulphuric-phosphoric acid baths which they recommend for the electrolytic polishing of 18/8 stainless steel and discuss the effects

of varying the current density and the immersion period.

Metal Cleaning and Ordnance Production. R. W. Mitchell. (Steel, 1941, vol. 109, Dec. 8, pp. 90-94, 117; Dec. 15, pp. 86-90; Dec. 29, pp. 54-56, 76). In this discussion of the theory and practice of metal cleaning the author first describes the requirements of a good cleaning agent, dealing in turn with wetting, penetration and alkalinity. In the second part he distinguishes between a physically clean surface which is satisfactory for painting or laquering and a chemically clean surface which is necessary for electroplating work. Pre-cleaning is now becoming standard practice for the removal of dirt, such as buffing and polishing compounds and cutting and stamping oils. Chemically clean surfaces are produced by suitable soaps or synthetic wetting agents, usually in mechanical washing machines. The application of the processes in ordnance production is dealt with in the third part. For the cleaning of shell forgings an emulsifying solvent is preferable to vapour degreasing; the former is used at room temperature, and this is followed by rinsing with hot water under pressure—the heat is not essential to the rinsing, but it ensures rapid drying.

Methods of Shell Cleaning. (Machinery, 1941, vol. 59, Dec. 25, pp. 354–355). The advantages and disadvantages of several types of tanks and solutions for cleaning shell forgings are discussed.

Semi-Continuous Pickler for Cleaning 24-Inch Strip. (Steel, 1941, vol. 109, Dec. 29, pp. 66-67). An illustration is given of a pickling plant recently put in commission in Detroit. It has a capacity of 10,000-15,000 tons per month. The plant is in one line, but it is designed to take two strips side by side, each with a maximum width of 24 in. Coils are pickled separately, i.e., without welding or stitching them end to end, and it is therefore called a semi-continuous plant. The pickling solution is in two tanks, the first smaller than the second, but with a higher acid concentration. Pipe-lines and control valves' are arranged so that the acid from the first tank can be pumped into the second one, where sufficient water and acid are added to make up the required volume and concentration. Spent solution from the second tank is pumped to a neutralising tank and thence to the town sewers.

Surface-Active Materials in Acid Pickling Solutions. D. S. Hartshorn jun. (Metal Finishing, 1941, vol. 39, Oct., pp. 561–563). The author discusses the addition of surface-active compounds to acid pickling baths. The effect of such compounds is to lower the surface tension of the solution, and thus to increase its wetting and penetrating power. An acid solution thus treated will therefore penetrate more rapidly into crevices and underneath scale. A saving of acid is also effected, because less acid will cling to the

work on removal from the bath.

A Suggested Method for Neutralizing Waste Pickling Acid Effluents. F. Smith. (Chemistry and Industry, 1942, vol. 61, Feb. 7, pp. 68–69). The author describes some experiments in which the use of waste sludge from a lime-soda water-softening plant to neutralise pickling-bath effluents was tested in the laboratory and found successful. In one experiment waste pickling solution containing $7\frac{1}{2}\%$ of H_2SO_4 by volume was diluted with water by adding diluted lime-soda sludge. The solution was then made alkaline to phenolphthalein by adding solid soda ash. It was seen that, if it is necessary to remove all the ferrous sulphate from solution, lime-soda sludge is of little value, but if the bulk of the ferrous sulphate can be left in solution, then the sludge is quite satisfactory.

COATING OF METALS

(Continued from pp. 101 A-107 A)

Specification Plating. C. B. F. Young. (Iron Age, 1941, vol. 148, Dec. 11, pp. 44–47; Dec. 18, pp. 59–65). The author discusses the theory of the electrolytic deposition of metals and describes nine methods of determining the thickness of metal coatings. A series of tables is also presented, from which the time required to produce coatings of eleven different metals at eleven current densities from 1 to 50 amp. per sq. ft. in twelve different thicknesses from 0·0001 to 0·003 in. can easily be obtained. The metals referred to are gold, brass (70/30), silver, tin, zinc, cadmium, copper, chromium, iron, nickel and cobalt.

Industrial Chromium Plating. A. Mankowich. (Metal Finishing, 1941, vol. 39, June, pp. 294–296). The author discusses the hard chromium plating of steel. For hard deposits the thickness is in the range 0·0003–0·050 in., but it should be at least 0·003 in. for heavy serivce. The solution the author prefers is made up of chromic acid 33 oz. per gal. and sulphuric acid 0·33 oz. per gal., and this is used at 130° F. with a current density of 400 amp. per sq. ft. The advantages of a chromic-acid pickling treatment after pickling in hydrochloric acid and immediately preceding the plating

are emphasised.

Effect of Wetting Agents on Electrodeposition of Nickel. R. F. Davis, K. M. Wolfe and W. G. France. (Industrial and Engineering Chemistry, Industrial Edition, 1941, vol. 33, Dec., pp. 1546–1548). The authors report on some experiments on the effects of six strong and three mild surface-active wetting agents when added to nickel-plating solutions. The wetting agents rapidly lowered the surface tension of the bath, which then remained fairly constant. The size of the nickel crystals decreased with increasing additions

of the wetting agent. The most satisfactory deposits were obtained

at a low surface tension of 30-35 dynes per cm.

Prevention of Nodular and Porous Nickel Coatings. R. J. Green. (Metal Finishing, 1941, vol. 39, Oct., pp. 559–560). The author refers to an investigation of the cause of rough and porous nickel coatings on steel. This was traced to the fact that the ground carbon and other filtering powders used were so fine that small quantities could pass through the pores of the retaining cloths and get back into the plating solution. Some of them were then trapped on the steel by the nickel deposit, thus causing the roughness.

The Cause of Gray Sheets in Hot-Dip Galvanizing. W. G. Imhoff. (Blast Furnace and Steel Plant, 1941, vol. 29, Nov., pp. 1124–1126, 1148–1149). The author discusses how changes in the processing of steel sheet affect the appearance after galvanising. The primary cause of grey galvanised coatings is that the uncoated surface is too rough. The rough surface is usually due to oxidising conditions prevailing in the earlier processes of sheet manufacture, and it provides pores which retain some of the hydrogen formed during pickling.

Electrolytic Zinc-Coated Wire. L. H. Winkler. (Wire and Wire Products, 1941, vol. 16, Nov., pp. 687–693, 712–715). The author gives a detailed and illustrated description of an electrolytic process of galvanising steel wire. This process is known as "bethanising," and descriptions of it have appeared in the

iterature.

Peculiarities of Zinc Electrodeposits. H. Fischer and H. Bärmann. (Zeitschrift für Metallkunde: Metal Finishing, 1941, vol. 39, Sept., pp. 471-478). The authors first report on an investigation of the different rates of attack of hydrochloric acid and of sodiumchloride solution on bright and dull electrolytic zinc coatings applied in acid and in alkali baths. Deposits from new solutions dissolved more rapidly in hydrochloric acid than did those formed in solutions that had been worked for longer periods; this difference was particularly marked with bright zinc coatings. The rate of attack was the same for plating in acid and in alkali solutions. Similar effects were observed with 3% sodium-chloride solution at 20° C. Bright coatings are more resistant to these corrosive solutions than dull ones. Tests on the physical properties of zinc coatings by X-rays and other means revealed that: (1) The structure of electrolytic zinc coatings from alkali baths has a preferred orientation but that from acid baths has not: (2) bright zinc coatings are very finegrained, but the grains are not as fine as the wave-length of light; their brightness must therefore be attributed to the preferred orientation; (3) the coarsest deposits were obtained from acid solutions; and (4) bright deposits from alkali baths showed pronounced cracks on drawing in an Erichsen cup machine, but acid-bath zinc deposits were ductile.

In conclusion, the factors affecting the embrittlement of steel

during galvanising were examined with the following results: (1) Plating in alkaline solutions produced hydrogen embrittlement whilst acid solutions did not; (2) the steel remained brittle even after removing the zinc coating, but after allowing time for the hydrogen to escape, the steel reverted to its original ductility; and (3) the reduction of the embrittlement is very slow at room temperature, but it can be rapidly removed by heating to about 300° C.; the success of this treatment depends upon the condition of the steel.

Possible Substitutes for Zinc Coatings on Steel. (American Iron and Steel Institute, 1941, Nov., Contributions to the Metallurgy of Steel No. 4). At the request of the Committee on Manufacturing Problems of the American Iron and Steel Institute, an informal committee of metallurgists selected from the Technical Committees of the Institute held several conferences for the purpose of studying possible substitutes for zinc coatings on steel. The report of this informal committee is now presented, and it is divided into the following sections: (1) Lead base coatings; (2) metals unavailable or of restricted availability; (3) non-metallic inorganic coatings; and (4) organic coatings.

A Survey of Modern Electro-Tinning. E. Armstrong. (Metal Treatment, 1941, vol. 7, Winter Issue, pp. 154–161, 167). The author describes electrolytic processes of tinning with baths of stannous chloride, stannous sulphate and sodium stannate, and gives tables of the results of salt-spray and of hot and cold humidity

tests on tin coatings formed by these processes.

Alkaline Tin Plating. Z. Irenas. (Monthly Review of the American Electroplaters' Society, 1941, vol. 28, Dec., pp. 975–982). The author describes the process of tinplating small parts in alkaline baths containing sodium stannate, sodium hydroxide,

sodium acetate and hydrogen peroxide.

American Hot-Dip Tinning Practice. Treatment of the By-Products of the Hot-Dip Tinning Process. W. G. Imhoff. (Metal Finishing, 1941, vol. 39, Nov., pp. 607-610). The author describes methods of recovering tin from the skimmings of tin-plating baths. Tin baths are usually boiled out or refined by pushing a log of green timber into the molten tin; the boiling action thus caused carries oxides, dross and dirt to the surface, where it is skimmed off. These skimmings contain tin shot and tin splashes. One method is to put the skimmings in a perforated, saucer-shaped scoop and work this back and forth over the tin bath. Sal ammoniac and rosin are mixed in and fumes are given off which are ignited; the heat generated melts out the pure tin, which falls through the perforations back into the bath. A second method is to treat the skimmings on a sloping plate over a low-temperature furnace. This should be heated with a slow, soft fire, and the temperature should be kept at about 460-475° F.-i.e., just above the melting point of tin. Small balls of tin melt out and run down the plate. The residue is covered with a shower of sal-ammoniac and powdered rosin and stirred vigorously; the smoke given off is ignited, and the heat assists in melting out the tin. Fresh skimmings are added from time to time and worked well with sal-ammoniac and rosin. Finally sufficient tin is collected to cast into a pig. A third method is to put all the skimmings in a large steel pot, fill it up with water and boil vigorously with a live steam line. The boiling water dissolves soluble materials, and the residue is treated in a furnace as in the second method.

Phosphate Pre-Treatments for Iron and Steel. E. E. Halls. (Metallurgia, 1942, vol. 25, Jan., pp. 69-74). The author describes in detail all the operations involved in phosphatising steel and the equipment required. He also presents and discusses test data on the corrosion resistance of various combinations of ground and finishing coats of paint and enamel on steel with and without pretreatment by phosphatising.

Metal Spraying—The British Wire Process. G. C. Pitcairn. (Metal Industry, 1942, vol. 60, Jan. 23, pp. 50-51). The author describes a wire-fed metal-spraying pistol, giving data on the consumption of combustible gas, oxygen and compressed air, and discussing the preparation of the surface to receive the spray, the structure of

the sprayed metal and the polishing of the finished surface.

Investigation of Fish-Scale Phenomena. W. W. Higgins and W. A. Deringer. (Journal of the American Ceramic Society, 1941, vol. 24, Dec., pp. 383-392). The authors describe an investigation of the influence of the following three factors on fish-scale formation in enamel coatings on iron and steel: (a) The manufacture and processing of the base metal before enamelling; (b) the clay in the enamel; and (c) the atmosphere in the enamelling furnace. They came to the following conclusions: (1) More fish-scales appear when specimens are enamelled on both sides than when enamelled on only one side; (2) fish-scaling is more likely to occur when pieces are fired in air than when fired in an atmosphere with controlled oxidation; excessive iron oxide at the interface destroys the bubble structure of the enamel and promotes fish-scaling; (3) a high water-vapour content in the furnace promotes fishscaling; (4) clear-firing clays tend to produce more fish-scales, and clays which produce a good bubble structure tend to reduce fish-scale formation; (5) cold-working the surface of the metal before enamelling reduces fish-scale formation; and (6) when a fishscale forms, gas is given off from that point, and it often continues to be evolved for several hours; this gas is almost pure hydrogen.

Protection against Corrosion by Painting. A. (Schweizerischer Elektrotechnischer Verein, 1941, Bulletin No. 15, Reprint). After quoting the example of Golden Gate Bridge, San Francisco, where the omission of sand-blasting on grounds of expense led to the flaking-off of paint after only one year, the author points out the necessity for the removal of all mill scale before painting structural steelwork. He then discusses two methods of removing scale, namely, sand-blasting and flame-descaling. For proper sand-blasting it is necessary to pay attention to the following factors: grain size of the sand, air pressure, size and direction of nozzle and distance of nozzle from the work. The surface must not be roughened too much, for in that case the paint will fill in the pits, and the ridges will project above the paint film. Cases have been known where. after two coats, rusty spots have appeared owing to the surface being too rough. The compressed air must be well dried and free from oil; the sand-blasting should only be done under cover in dry weather. The surface should be well brushed to remove dust and the ground coat applied within two hours. Painting should not be done in the same shop as the sand-blasting; when a fixed structure is being treated, wet sacking can be hung between the sand-blasting and the painting positions. Under certain circumstances steel grit can be used instead of sand.

The Swiss State Railways have been testing descaling with a welding torch. The application of this causes most of the scale to fly off; the remaining scale and rust are reduced and melted into the surface of the steel and a scarred surface is thus formed. A flame-cleaned surface is not so mechanically clean as a sand-blasted. one, for a hard oxide layer is formed in addition to the small spots of melted-in scale and reduced rust; this oxide layer is porous and quite distinct from mill scale. A two-year test on flame-descaled steel which had been given a ground coat of red lead showed that the adhesion was still good and that there was no rust whatever underneath. On scratching through the red lead corrosion did not spread laterally underneath it. For good flame-descaling a high flame intensity with consequent high velocity of the gases is required. the regulations of the American Institute for Steel Construction it is laid down that about equal quantities of acetylene and oxygen should be fed to the burner and that the proportion of the length of the inner cone of the flame to that of the whole flame should be 1 to 8. Special burner heads have been developed in America which are up to 15 cm. wide and carry many small nozzles 4 mm. apart. The flame is held at about 60° to the work, as this causes the loosened scale to be blown away and prevents overheating of the burner head by reflected heat. The burner is advanced across the surface at the rate of about 9 m. per min. Loosened particles must be removed with a wire brush and the surface must then be dusted with an old paint brush. The ground coat should then be applied on the still warm surface. It is very costly to remove grease, oil and old paint with the burner, so that in such cases some form of precleaning is worth while. The Golden Gate Bridge is now being cleaned by flame-descaling, as sand-blasting and other methods cannot be applied to this complicated structure. Flame-descaling is not to be regarded as a universal method, but rather as one to be used under special circumstances.

The author next considers the characteristics of water-resisting and weather-resisting top coats. Experience has shown that only a few coating materials, e.g., dried oils and oil-treated synthetic resins, can be called weather-resisting. When light rays fall on the surface, the life of paint will be prolonged if light-reflecting pigments such as aluminium powder and micaceous iron ore are added. It is thought that a combination of white lead and micaceous iron ore would give excellent results. Tests with specimens exposed to the south at an angle of 45° to the horizontal have shown that the proportion of micaceous iron ore in the mixture is very important; it is only when this proportion is 60% that a better life is obtained than with white lead alone, and this is true irrespective of the climate. The addition of such pigments is specially recommended for finishing coats of paints, such as chlorinated rubber, bitumen and tar, which are very sensitive to the sun's rays. Oil paints are not very water-resisting, as the oil film swells. Bituminous lacquers and emulsions have remained quite unaffected after six years' immersion in water. It is an interesting fact that paints of very similar chemical composition often behave very differently; for instance, one chlorinated-rubber coating was proved excellent after a six-year test, whilst a similar one failed very quickly. The nature of the water used for testing is also very important; an English bituminous paint lasted well for five years at Eglisau testing station, but was no use after three years at Mühleberg—it is thought that the Mühleberg water contains bacteria which decompose bitumen.

Some illustrations are presented of three specimens, BV, BIX and BXI; half of each plate had a ground coat containing red lead and the whole surface had a top coat of a bitumen varnish. All three were exposed alternately to the action of water and air, specimen BV to Aare water and to air without sunlight, specimen BIX to Rhine water with sunlight and specimen BXI to Aare water with sunlight. The coating all over the first one remained in excellent condition. That portion of the second one which had no ground coat was slightly cracked but no varnish had flaked off, whilst the varnish over the red-leaded area was covered with cracks. On the third one the bitumen direct on the iron had partly flaked off, whilst that on the red lead was completely washed off. The difference between specimens BIX and BXI is thought to be due partly to the fact that Rhine water deposits a protective coating of lime. These tests illustrate the danger of the possible early failure of a bitumen varnish on a red-lead ground coat and they also show that oil paints are not suitable for continuous immersion in water, whereas bitumen and chlorinated-rubber paints are water-resistant, but soon age when exposed to the sun unless they contain a reflecting pigment.

PROPERTIES AND TESTS

(Continued from pp. 150 A-158 A)

The Mechanical Testing of Wire and Some Related Phenomenon. G. Robinson. (Wire Industry, 1942, vol. 9, Jan., pp. 21–26). The author explains the terms used in the tensile testing of wire, showing how the elongation and reduction of area are calculated. He relates the terms "simple slip" and "complex slip" to the stress-strain curve, and considers how cold work affects the test results.

Notched-Bar Tensile Tests with Superimposed Bending Stresses. H. Kiessler and W. Connert. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, May, pp. 555-559). The authors investigated the behaviour of notched specimens of three low-alloy aircraft steels under the simultaneous application of tensile and bending stresses. This question is of importance because in the finishing and assembly work undesirable bending stresses may be imposed on engine parts, the effect of which cannot be foreseen. The two kinds of stress were applied in a tensile machine by placing under the head of the specimen a washer the faces of which were not parallel; this caused non-uniform stressing with the maximum stress at the thickest part of the washer. Washers with faces at different angles up to 13° were used. The higher the tensile strength of the material, the greater was the reduction in the notched-bar tensile strength with increasing bending stress. With specimens of low and of high tensile strength variations in the notched-bar impact strength had little effect on the notched-bar tensile strength, but with medium tensile strength of about 100-130 kg. per sq. mm. the impact strength had a marked effect on the notched-bar tensile strength. The cause of this change in the behaviour of steel of different tensile strength conferred by different heat treatments is attributed to changes in the resistance to deformation. Diagrams and illustrations are presented which demonstrate the effects of different shaped notches on the test results and on the appearance of the fractures.

Tensile Tests with the Prevention of Slip. H. Schule. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Apr., pp. 513–520). In previous investigations of the relation between the deformation resistance of steel and its ductility the cutting of notches was applied to increase the deformation resistance, so that rupture took place after only slight deformation. In the present investigation the effects of increasing the resistance to slip by two other methods are examined, namely, by decreasing the temperature and by high deformation velocities. The tests were made on specimens of a 0·14% carbon steel. Specimens with rounded notches of different radii were first tested at room temperature, then after ageing and tempering, and finally at low temperatures. The rup-

ture strength of the specimens decreased as the amount of deformation increased. When the deformation resistance was increased by either ageing or lowering the temperature, the rupture strength was only slightly affected. Unnotched specimens were then strained by different amounts at room temperature and then pulled to fracture at -182° C. These conditions did not bring about a fully brittle fracture; the deformation resistance was increased under these conditions by about 50 kg. per sq. mm., but the deformation of 5–10% which occurred before fracture changed the conditions of slip to such an extent that no maximum rupture strength could be determined. Additional tests were made at - 182° C. on a 0.02% carbon steel. The third series of tests were made on specimens with rounded notches on an impact machine at room temperature, and a special device was used to measure the maximum stress applied. The specimens were first subjected to various degrees of deformation at room temperature, but in this series too it proved impossible entirely to prevent deformation during the impact tests. The rupture strength of specimens which had been subjected to previous severe deformation was found to average about 160 kg. per sq. mm.

The tests on notched specimens confirmed the conclusion of Kuntze that the rupture strength of a steel decreases with the amount of deformation because the ability to slip has been destroyed, and a satisfactory explanation can be given for the results of tests at — 182° C. which did not conform with this. The rupture strength of previously deformed specimens could be established by impact tests. A comparison of the results obtained by the different methods of testing show how difficult it is to obtain a picture of the changes in rupture strength of specimens previously subjected to different

degrees of deformation.

The Behaviour of Deformed Metals under Tensile Stress. F. Körber, A. Eichinger and H. Möller. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 9, pp. 123-133). It has been observed that if cylindrical specimens of steel are deformed by longitudinal compressive stresses they will exhibit a considerable reduction in ductility under subsequent tensile stresses. In the present paper the authors report on an investigation of this phenomenon using specimens of dead mild steel, cast steel and brass. With all three materials, after 50% deformation by the tensile-wedge method, the reduction of area in subsequent tensile tests was less than 3%. An X-ray investigation showed that, in addition to ageing, there was another reason for the brittle behaviour of the deformed metal; this was that the longitudinal cold-deformation gave the crystallites an orientation which was unfavourable for resisting subsequent tensile stresses. If the compressive stresses were applied perpendicular to the direction of the tensile stress, this could produce a favourable orientation, and thus improve the tensile properties.

The Effect of Corrosion on the Strength Properties of Metallic Materials, Especially Cast Iron. W. Patterson and E. Piwowarsky. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, May. pp. 561–570). The authors review the literature on the effects of previous and simultaneous corrosion when subjecting steel to tensile and fatigue tests, and present additional information on similar tests with ascast and machined specimens of grey iron with carbon varying from 1.6% to 3.8%. With cast iron the strength properties were only slightly affected by corrosion. With static stresses and simultaneous corrosion by tap-water, sea-water, or a solution of common salt, no dangerous reduction in strength took place in the range of stress to which cast iron is ordinarily subjected, but there was a marked reduction in the bending fatigue strength with simultaneous corrosive attack.

Residual Stress in SAE X4130 Steel Tubing. G. Sachs and C. H. Campbell. (Welding Journal, 1941, vol. 20, Nov., pp. 553-S-558-S). The authors describe an investigation of the residual stresses in a chromium-molybdenum steel tubing 7 in. in outside dia. with a wall thickness of 0.034 in. Lengths between 11 and 2 in. were cut off and subjected to heat treatment. The stresses were then determined from measurements of the increase in diameter after splitting, and from the deflection of narrow longitudinal tongues. It was discovered that residual stresses up to 50,000 lb. per sq. in. may be present in normalised, low-alloy steel tubing having a tensile strength of about 100,000 lb. per sq. in. These stresses are distributed similarly to those produced by oil-quenching, and are characterised by high tensile stresses at the inner and outer surface, changing to compressive stresses at the centre of the wall. The residual stresses in this class of tubing may be sufficiently unbalanced to cause slitting after heat treatment in industrial furnaces owing to non-uniform cooling, but this did not happen in the laboratory furnaces used in this investigation.

A Method of Defining Failure in Members Subjected to Combined Stresses. J. Marin. (Transactions of the American Society for Metals, 1941, vol. 29, Dec., pp. 1013–1021). The author presents a method for defining failure when testing structural members by the application of combined stresses where the material considered has no definite yield point. The method is based on the assumption that failure under combined stresses occurs when the maximum principal strain is equal to the value of strain when failure occurs

in the case of simple tension.

Metallurgical Features of Coupling Pins. A. Wells. (Heat Treating and Forging, 1941, vol. 27, Nov., pp. 578-579). The author studied the cause of the frequent breakage of steel coupling pins 1½ in. in dia. and 18 in. long used to couple haulage cables to quarry trucks. This was found to be the extension of fatigue cracks originating at notches in the soft surface. The use of machined pins of a high manganese steel or of a chromium-vanadium steel increased their life many times.

The Damping of Cast Iron under Tensile-Compression Stresses. M. Hempel. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Apr., pp. 505–511). This paper in an abridged account of Pomp and Hempel's investigation of the fatigue strength of cast iron and malleable cast iron which appeared originally in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 11, pp. 169–201. (See Journ. I. and S.I., 1941, No. II., pp. 216 A).

The Importance of the Elastic Limit with Regard to the Fatigue Strength of High-Strength Steels. A. Fry, A. Kessner and R. Oettel. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, May, pp. 571-576). The authors investigated the relation between the tensile properties and the bending-fatigue strength, damping capacity and repeated impact strength of six chromium-molybdenum and chromium-nickel steels. It was noted that with the lower-strength steels the fatigue strength increased with increasing elastic limit. But with the steels of about 120 kg, per sq. mm. tensile strength an increase in the elastic limit had no effect on the fatigue strength. Steels of about 150 kg. per sq. mm. tensile strength, however, had a lower fatigue strength with increasing elastic limit. The raising of the elastic limit decreased the capacity of the steel to transmit stress increases to less stressed areas, and thus increased the risk of fatigue fracture in these high-strength steels. On the basis of these results a new formula was developed for the approximate determination of the fatigue strength from the tensile strength and elastic limit. In general, raising the elastic limit of high-tensile steels, whether by heat treatment or by the addition of alloying elements, is more likely to lower the fatigue strength than to raise it. A high elastic limit is particularly dangerous in the case of repeated impact stresses. Parts such as crankshafts and connecting rods must have a high damping capacity, and it is advisable to aim at having good damping properties in steels for these parts, even if it means some sacrifice in fatigue strength.

The Behaviour of Steel at Low Temperatures under Tension-Compression Fatigue Stresses. M. Hempel and J. Luce. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 5, pp. 53-79). After reviewing the literature on the properties of steel at low temperatures, the authors describe the apparatus they set up for making tension-compression fatigue tests on steel at temperatures down to about - 190° C., and discuss the results obtained on plain and notched specimens of three chromiummolybdenum aircraft steels and three carbon steels containing respectively 0.08%, 0.40% and 0.64% of carbon. The Wöhler curves for different mean stress values were approximately parallel for the different testing temperatures, but the shape of the curves at the fatigue limit end differed somewhat for the different temperatures and specimen shapes. It was observed that the fatigue tests on both plain and notched specimens could be run at much higher mean stresses at low temperatures than at room temperature. Contrary to plain specimens, it was noted that as the mean stress applied to notched specimens was increased the stress range had to be decreased.

The fatigue strength of both plain and notched specimens increased with increasing tensile strength of the steel. The increase in the fatigue strength of plain specimens in the temperature range -78° to -188° C. was very marked, whilst the increase in the case of notched specimens with falling temperature was not so great. The notch sensitivity of unalloyed steels increased very considerably with falling temperature, especially in the region of -188° C.

The Influence of Surface Films on the Dry and Lubricated Sliding of Metals. T. P. Hughes and G. Whittingham. (Transactions of the Faraday Society, 1942, vol. 38, Jan., pp. 9-17). The authors describe an experimental investigation of the effect of various surface films on the friction between metals under ordinary atmospheric conditions. The apparatus used was a smaller copy of that of Bowden and Leben in which the rapid fluctuations in frictional force were followed by having the upper slider of low inertia and mounted on a high-frequency bifilar spring system. The sliding behaviour of various pairs of metals was examined; these included molybdenum on stainless steel, mild steel on aluminium, mild steel on mild steel and stainless steel on stainless steel. The surface films tested were oxide and sulphide layers, and selenide, phosphide, chloride, iodide, graphite and molybdenite films. In all cases the presence of a surface film considerably reduced the friction. The sliding behaviour is classified into four types, and the degree of reduction in friction and the type of sliding under the conditions described are given in tables.

The True Specific Heat of Pure Iron and Iron-Carbon Alloys from 20° to 1100° C. H. Esser and E.-F. Baerlecken. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, June, pp. 617-624). The authors describe two forms of apparatus which they developed for measuring the specific heat of electrolytic iron and of iron-carbon alloys at different temperatures, and present the results obtained in tables and graphs. In the first, the sample is in the form of a spiral coil in the centre of an electric resistance furnace. The furnace brings the coil up to the desired testing temperature, and a current is then passed through the spiral and the pressure, amperage, duration of the current and increase in temperature of the wire are carefully measured. In the second method, the specimen is in the form of a cylinder with a hole in one end; this is also placed in a resistance furnace to bring it to the testing temperature, but the additional heat for the specific heat determination is supplied by a small coil of tungsten wire wound on a quartz tube, which is inserted in the hole in the specimen. A table of the specific heats of electrolytic iron and of thirteen iron-carbon alloys (carbon 0.075% to 3.36%) at temperatures advancing in 20°-stages from 20° to 1100° C. is presented.

Oxygen in Cast Iron. G. Veynberg. (Stal, 1940, No. 8, pp. 38-41). (In Russian). Analyses by the author showed that grev cast irons produced by using coke fuel contained from 0.018% to 0.027% of oxygen; foundry irons produced with charcoal in the blastfurnace contained from 0.014% to 0.019% of oxygen; Swedish charcoal foundry irons from 0.013% to 0.016% of oxygen; iron castings from 0.038% to 0.054% of oxygen and malleable cast iron from 0.014% to 0.027% of oxygen. In a series of foundry cast irons the oxygen content tended to increase with the silicon content whilst the manganese content did not exert any obvious influence. In blast-furnace metal the oxygen content tended to increase with increasing pressure and temperature of the blast. Values for the oxygen content of different cast irons obtained by previous investigators are summarised and reference is also made to the hydrogenreduction method of determining oxygen in cast iron. As modified in certain respects by the author, the method is shown by comparative tests to give results in good agreement with those obtained by the hot-extraction vacuum method.

The Mechanical Properties of Molybdenum-Free Case-Hardening and Heat-Treatable Steels. A. Pomp and A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 10, pp. 135–185). The authors report on an extensive investigation of the hardenability, tensile and impact strengths of a carbon steel and of a number of alloy steels not containing molybdenum; the latter were alloyed with manganese, chromium, manganese and silicon, manganese and chromium, chromium and vanadium, and manganese and vanadium. Specimens of each steel 15, 30, 60, 90 and 100 mm. in dia. were supplied by three different steelworks, and the object was to determine whether the requisite properties could be obtained without the use of molybdenum. The results of many series of tests are given in extensive tables. It was found that the required standard of strength in both the core and the surface could be produced for most of the heat-treatable steels.

Investigation of the Properties of Bessemer Steel Rails Subjected to Controlled Cooling. A. Makhanek. (Stal, 1940, No. 8, pp. 35–37). (In Russian). Tests were made on specimens of Bessemer steel rails cooled in air in the ordinary way and cooled in air to respectively 600°, 500° and 400° C., followed by slow cooling (in 12–14 hr.) to 80–100° C. Tests showed that slow cooling had no noticeable effect on the tensile properties, hardness and notched-bar impact strength; it did, however, reduce the resistance of unnotched specimens to repeated impact.

Choice of Steel Composition for High-Pressure Cylinders used for Automobiles. N. Dukhan and S. Otin. (Stal, 1940, No. 8, pp. 46–48). (In Russian). High-pressure gas cylinders used to carry gaseous fuel on automobiles were produced from a low-alloy nickel-chromium-molybdenum steel, heat-treated to give 100 kg. per sq. mm. ultimate tensile strength; from a 0·45–0·54% carbon steel heat-

treated to 80–90 kg. per sq. mm. and from Chromansil steel (carbon 0.31–0.35%, manganese 0.9%, silicon 1.01–0.16%, chromium 0.91–0.93%, phosphorus 0.26–0.03%, sulphur 0.023–0.025%) heattreated to give an ultimate tensile strength of about 90 kg. per sq. mm. In addition to determining the tensile properties of the materials, all cylinders were subjected to pneumatic and hydraulic tests, and were all found to meet official standards. The two alloy steels were superior to the carbon steel, in that they did not shatter when pressure-tested to destruction. The carbon steel cylinders were rejected on those grounds. On the whole, the use of the

Chromansil steel is preferred. The Present Status of Chilled Iron Rolls. A. Allison. (Foundry Trade Journal, 1942, vol. 66, Feb. 12, pp. 105-106: Iron and Coal Trades Review, 1942, vol. 144, Jan. 23, pp. 75-76). The author discusses different aspects of the manufacture of chilled cast-iron rolls. No specification has yet been devised for chilled rolls except the surface hardness as measured by the Shore scleroscope. No test-piece can be excised or detached; the ultimate resort, therefore, is statistical or bulk research, as has been applied to ingot moulds. The author deals separately with the influence of carbon, manganese, silicon, sulphur and phosphorus. In considering cooling characteristics and the formation of a deep zone of mottled iron behind the chill, reference is made to the practice of some large sheet-mills where the roll is used for finishing until most of the chill is worn off; the remainder of the chill is then turned off and the fine mottled surface is then very satisfactory as a roughingmill surface. The deeper zone is naturally produced by alloying elements which slow up the change points. In rolls of the semichill type the working surface is really a very fine mottled iron with fine graphite, producing a durable quality excellent for many purposes, although softer than that of a fully chilled surface. To produce martensitic chill, a nickel content of 3% is required with corresponding 1% of chromium in medium-sized rolls. The hardness required by service can thus be produced by adjusting the alloy content to the size of the roll. There seems to be general agreement that for the working rolls of four-high cold mills, hollow rolls in alloy cast iron do not possess sufficient fatigue resistance, so that the central cooling chamber must be dispensed with.

All-Black Malleable Iron in Theory and Practice. M. Wildermann. (Giesserei, 1941, vol. 28, May 30, pp. 252–255). The author describes some tests of the behaviour of all-black malleable iron when used as a bearing metal. Theoretical considerations led to the belief that this class of iron should only be used for bearings when $p \times s < 22$, where p is the pressure on the bearing in kg. per sq. cm. and s is the surface speed in m. per sec. Many tests carried out by the author, which are described in detail, showed that all-black malleable iron bearings could be used even when the pressure

was high, provided that the speed was low. The combination of high speed and high bearing pressure necessitated lining the bearing with a thin layer of anti-friction alloy. If the lining was destroyed it was only in extreme cases that the malleable iron would score the shaft.

Basic Bessemer Steel Killed with Silicon and Aluminium for Ships' Rivets. H. Hauttmann. (Iron and Steel Institute, 1942, Translation Series, No. 70). An English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, Aug. 28, pp. 801–806. (See p. 69 A).

Alternate Steels for Emergency Use. (Machinist, 1942, vol. 85, Jan. 24, pp. 1039–1050). Information is given on the analyses, heat treatment and properties, including machinability, of lowalloy and other special steels available in America as substitutes for high-alloy steels, particularly those high in nickel or tungsten.

Steel Specifications and Their Interpretation. A. J. K. Honeyman. (Journal of the West of Scotland Iron and Steel Institute, 1941–42, vol. 49, Part I., pp. 5–14). The author discusses the tests on which specifications for steel are based, dealing in turn with tests which give information on bending, rigidity, strength, toughness, ductility, weldability, corrosion resistance, accuracy of dimensions, and composition. In conclusion a tentative specification for boiler steel is put forward.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 158 A-160 A)

The Determination of Elasticity Constants by X-Rays. H. Möller and H. Neerfeld. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 7, pp. 97–104). The authors endeavour to find an explanation of the differences which have been observed between stress determinations made mechanically and by X-rays. Bruggeman's view as to the arrangement of the crystallites in an aggregate corresponds better with experiment than the views of Voigt and Reuss. The calculations pointed to the assumption that the direction of measurement affected the elastic constants determined by X-rays. The values also depend on the particular set of planes adopted for the calculation.

X-Ray Diffraction as a Method of Identifying Metal Alloys. L. L. Wyman. (Steel, 1941, vol. 109, Dec. 22, pp. 70-72; Dec. 29, pp. 62-65). After describing in simple language bodycentred and face-centred lattice structures, the author explains the theory of the X-ray diffraction technique by which the lattice type can be recognised and its size measured. Some practical examples of the application of this technique to the study of alloys and

corrosion products are given.

X-Raying Welded Pressure Vessels. A. J. Moses. (Welding Engineer, 1941, vol. 26, Dec., pp. 19-23). Ten Years' Progress in Radiography. (Metal Progress, 1941, vol. 40, Nov., pp. 771-776). The author reviews the development of X-ray apparatus for the examination of welds in boiler drums and other pressure vessels. The first X-ray equipment used at a works in the United States was a 2-valve, 200-kV., air-cooled apparatus; this was followed by installations of 300, 400 and finally 1000-kV. equip-The first proved suitable for testing steel up to 2 in. thick, whilst with the latest machine welds in boiler drums 51/4 in. thick have been satisfactorily tested with exposures of only 15 min. Some curves are presented showing the relation between plate thickness and exposure time for the 300, 400 and 1000-kV, installa-

The Lattice Spacings and Crystal Structure of Cementite. W. Hume-Rothery, G. V. Raynor and A. T. Little. (Iron and Steel Institute, 1942, this Journal, Section I.). Cementite was extracted by electrolytic attack from three steels of different compositions, and the lattice spacings were determined by Debye-Scherrer photographs in a 19-cm. camera. The values obtained were a = 4.5155 Å, b = 5.0773 Å, c = 6.7265 Å at 25° C., and differed from those previously given by Lipson and Petch (see Journ. I. and S.I., 1940, No. II., p. 95 P), whose specimen had partly decomposed during annealing. No difference could be detected between the lattice spacings of the three different samples, and the analysis of one of them confirmed the composition Fe₃C. The structure is discussed, and a possible mechanism is suggested for the formation of cementite from martensite.

On the Carbide and Nitride Particles in Titanium Steels. W. Hume-Rothery, G. V. Raynor and A. T. Little. (Iron and Steel Institute, 1942, this Journal, Section I.). A microscopic examination has been made of the structures of titanium steels containing from 0·1 to 1·0% of earbon and from 0 to 6·0% of titanium. Special attention was paid to the nature of the impurity constituents which are usually referred to as particles of titanium nitride. These were shown to consist of a whole series of particles ranging from yellow → orange → brown to grey, the grey particles being almost indistinguishable from those of titanium carbide, TiC. The general effect of increasing carbon content was to change the predominant colour from yellow to grey, but the particles in any one steel were very variable, and duplex or rimmed particles were often observed with yellow or orange interiors and brown or grey rims.

Residues were extracted from the steels by electrolytic attack in hydrochloric acid, and were submitted to chemical analysis and X-ray examination. The chemical tests showed that the yellow, orange and brown particles were attacked by chlorine at 300° C. with the liberation of free carbon and formation of volatile titanium tetrachloride, whereas titanium carbide is unattacked and titanium

nitride is attacked with the formation of volatile titanium chloride. The analyses suggested that in the orange and brown crystals some

of the nitrogen of titanium nitride was replaced by carbon.

The X-ray investigation of the residues showed that the yellow, orange and brown crystals gave rise to diffuse diffraction lines corresponding to face-centred cubic structures with lattice spacings between those of TiC and TiN. The diffuseness of the lines varied greatly in different residues. The microscopic, analytical and X-ray results all agree with the hypothesis that a continuous series of solid solutions exists between TiC and TiN, and that a given steel may contain certain particles of widely different compositions.

Nucleation and Growth Rates of Pearlite. J. E. Dorn, E. P. De Garmo and A. E. Flanigan. (Transactions of the American Society for Metals, 1941, vol. 29, Dec., pp. 1022–1036). Avrami has recently suggested that nuclei of a new phase may not form spontaneously, but that they originate from a finite number of germ nuclei; as transformation proceeds, the germ nuclei disappear, due to the fact that they mature and grow into nodules, or because the growing nodules absorb the germ nuclei as they spread over the old phase. In the present paper the authors describe a study of the growth and nucleation of pearlite in a eutectoid steel in an attempt to check the theories of Avrami and of Johnson and Mehl. From the data obtained it was concluded that, for the steel tested, . the nucleation and growth constants of pearlite were independent of time for the first half of the total reaction period. Theoretical determinations of the fraction transformed from nucleation data agreed reasonably well with the experimental results, but deviations between theoretical and experimental data were noted when the proportion transformed exceeded 65%. Avrami has suggested that the rate of pearlite formation is isokinetic, but this was not the case with the steel referred to in the present investigation.

The Development and Control of Engineering Grey Cast Irons. R. A. Flinn and D. J. Reese. (Foundry Trade Journal, 1942, vol. 66, Jan. 8, pp. 19–22; Jan. 15, pp. 37–38; Jan. 22, pp. 53–54, 52). The authors summarise the results of an extended investigation of the properties of grey cast iron which was begun at the research laboratories of the International Nickel Co., and continued at the Massachusetts Institute of Technology. The properties and control of the shape, size and distribution of the graphite are dealt with in Part I. The control of the matrix structure, with special reference to the S-curves, is examined in Part II. The authors come to the following conclusions on the cooling phenomena of grey cast iron with compositions in the range total carbon 2-0–3-5%, silicon 1-0–2-0% and manganese 0-40–1-00%: (1) Crystals of iron with up to 1-7% of carbon in solution precipitate between 1148° and 1093° C. (2) At about 1093° C. a mixture of carbide and austenite solidifies in the spaces round the first austenite crystals. (3) Changes in these solids take place down to 732° C. as follows:

(a) The carbide crystals, if present round the first austenite crystals, change to the grain-boundary type of graphite. (b) The amount of carbide soluble in austenite decreases with decreasing temperature from about 1.7% to about 0.85% at 732° C. If the silicon/carbon ratio is correct, this carbon is precipitated on graphite already present. If this ratio is too low, free carbide crystals will be present. If it is too high, free ferrite will separate. (4) At 732° C. the correct structure should be graphite and austenite with 0.80% of carbon in solution. From this point, if the cooling rate is slow and there is little alloying element present, a mixture of coarse carbide plates and ferrite will separate at 732-700° C. With more rapid cooling and/or alloy addition, the austenite will not transform until about 593° C. is reached, and fine pearlite will result. If the effect of cooling rate + alloy content is increased so that no pearlite is formed, no transformation will take place until either about 426° C. or 200-148° C. If molybdenum is present, the austenite will transform to an acicular structure at 426-315° C., and if molybdenum is absent, austenite may transform to martensite at 204-37° C. If the alloy content is sufficiently high and the cooling rate sufficiently great, austenite will persist to room temperature. This austenite may transform at still lower temperatures such as

that of liquid nitrogen.

Transformations During the Tempering of Chromium-Bearing Substitutes for Stainless Steel. A. Gulyaev. (Stal, 1940, No. 8, pp. 42–45). (In Russian). The steel $E\tilde{I}172$ investigated contained carbon $1\cdot06\%$, silicon $1\cdot53\%$, chromium $11\cdot05\%$, and vanadium $2\cdot0\%$. Some experiments were also made with steel EI173 containing carbon 0.91%, silicon 0.40%, chromium 9.48%, tungsten 2.02% and vanadium 1.20%. The effect of the quenching temperature on the behaviour of the steel during subsequent heating, the effect of the tempering temperature and the holding time, also the behaviour on repeated tempering, and the effects of quenching in liquid oxygen as well as of interrupting the martensite transformation, were investigated by dilatometric analysis supplemented by magnetometric determination of the residual austenite. The critical temperature of steel EI172 is about 1000° C.; a quenching temperature of 1200° C. was adopted. In the quenched state the steel consists of austenite, martensite and carbides, the proportions of these phases depending on the quenching temperature and time at that temperature. On heating to the tempering temperature, tetragonal martensite changes to cubic martensite at 150-250° C., this change being most marked in the steel quenched in liquid oxygen. On further heating, carbides precipitate from the austenite at temperatures between 500° and 600° C. and, on subsequent cooling, the secondary martensite transformation sets in at a temperature which is the higher the more complete the precipitation of carbides from the austenite. Repeated tempering leads more readily to transformation of the austenite than one prolonged tempering. Experiments with steel EI173 showed, however, that repeated tempering at $550{\text -}600^\circ$ C. markedly reduces the hardness. Providing accurate temperature control is available, it is therefore advisable to temper at a comparatively high temperature (550–560° C.) and to reduce the number of tempering treatments.

The Systems of the Metals of the Iron Group with Titanium, Zirconium, Niobium and Tantalum. H. J. Wallbaum. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Apr., pp. 521–526). The author reports the results of metallographic and X-ray investigations of the binary systems formed by one of the elements manganese, iron, cobalt and nickel with elements of the fourth and fifth groups of the periodic system, i.e., with titanium, zirconium, niobium and tantalum. It was established that in the binary systems of manganese, iron and cobalt compounds of the type AB_2 occur, but nickel forms compounds of the type Ni_3 Ti. In the iron-zirconium, cobalt-niobium and cobalt-tantalum systems an additional phase (the η -compound) was established when there was an excess of about 7% (atomic) of iron or cobalt; it crystallises after a peritectic reaction.

MINERAL RESOURCES

(Continued from p. 169 A)

Bauxite Resources of the United States. J. R. Thoenen and E. F. Burchard. (United States Bureau of Mines, 1941, Nov., Report of Investigations No. 3598). The authors present a report of an investigation the object of which was to ascertain as accurately as possible the total tonnage of bauxite reserves available in the United States.

Occurrences and Uses of Dolomite in the United States. S. F. Colby. (United States Bureau of Mines, Nov., 1941, Information Circular No. 7192). The present Information Circular incorporates the data published in Information Circular No. 6524 in 1931 on the dolomite reserves and the industrial application of dolomite in the United States and includes data resulting from more recent

investigations.

The Mineralogical Possibilities of Africa. F. Schumacher. (Stahl und Eisen, 1941, vol. 61, Dec. 18, pp. 1141–1148). In this review of the mineral resources of Africa special attention is paid to the iron and manganese ores. Most of the iron ore is in North Africa; it is low in phosphorus and is sent to Europe for smelting; the South African ores form the basis of the iron and steel industry of the Union. There are also iron reserves in the west coast areas. The manganese ore production in North, West and South Africa forms almost a quarter of the production of the whole world. Of the alloying elements for steel which are produced in Africa, chromium takes first place and this is followed by cobalt and vanadium.

The Coal Resources of the Japanese Empire. (Engineering and Boiler House Review, 1942, vol. 55, Mar., pp. 292–296). A review is presented of the resources, distribution, production and applications of coal in the Japanese Empire. "Greater Japan" possesses total coal reserves amounting to about 20,000 million tons, of which about one-half can at present be considered as economically exploitable. Coal statistics for 1932 and 1936 are compared, and it is seen that a rise of 54% in consumption took place in this period. In 1936 the heavy industries consumed about 6.48 million tons and 2.04 million tons were used for gas and coke production. Manchukuo is the most important coal-producing country in the Far East; the production in this province has risen from 9.07 million tons in 1933 to 21.63 million tons in 1940.

REFRACTORY MATERIALS

(Continued from pp. 170 A-172 A)

Second Report on Refractory Materials. (Iron and Steel Institute, 1942, Special Report No. 28). This Report, comprising 168 pages, is divided into four main sections A, B, C and D, the first of which consists of a foreword explaining the scope of the Report and lists of the members of the various committees and panels. The second and third sections deal with steelworks and blast-furnace refractories respectively, and the fourth section consists of a summary of other recent papers issued through the Bulletins of the British Refractories Research Association on basic refractories, the action of slags, vapours and gases on refractory materials, and on other work of interest to the iron and steel industry. Abstracts of the six individual papers contained in

Sections B, C and D are given below.

The Work of the Open-Hearth Refractories Joint Panel, 1939-1942. (Iron and Steel Institute, 1942, Special Report No. 28, pp. 7-11). A review of the work done in the last three years by the Open-Hearth Refractories Joint Panel of the Iron and Steel Industrial Research Council and the British Refractories Research Association is presented. The field covered is dealt with in three sections. Investigations on silica bricks have developed from a general survey to an intensive study of one roof; work on basic refractories has ranged from fundamental studies on the constitution of stabilised dolomite and chrome ores, to the preparation of test-sheets for the service testing of basic refractories in the open-hearth furnace; casting-pit refractories have several times been discussed in general terms, but now a sub-committee has been formed to deal with this side of the Panel's work. These three phases of the work, which have proceeded concurrently, are considered separately in the present review.

A Study of the Reactions between Dolomite and Various Minerals. Part I.—The Constitution of Fired Clinkers. J. R. Rait and A. T. Green. (Second Report on Refractory Materials, Iron and Steel Institute, 1942, Special Report No. 28, pp. 13–47). Moulded mixtures in various proportions of dolomite with flint, steatite, bentonite, china clay, olivine, serpentine, open-hearth slag, alumina, ferric oxide, zircon, baddeleyite, zirconia, rutile, chromite and chromium oxide have been fired at 1500° C. Qualitative tests for the presence of free lime in the fired clinkers have been made and quantitative determinations carried out on numerous samples. Measurements have also been made of the index of hydration of

the clinkers.

From a consideration of the relevant phase-rule diagrams,

assuming that the reactions in the clinkers had proceeded to equilibrium, the probable constitutions of the fired mixtures were calculated. The results of these calculations have been substantiated by (a) comparison of the calculated and experimentally determined free lime contents, (b) the dusting of those clinkers which calculation indicated contained a high percentage of calcium ortho-silicate, (c) by the form of the curves obtained by plotting the steam hydration indices against percentage of acidic oxides.

In all the clinkers it was assumed that all the magnesia was present uncombined as periclase. With increasing addition of silica or siliceous minerals the evidence indicated the increasing combination of the lime to form, first, tricalcium silicate and, with larger silica contents, dicalcium silicate. There was evidence for the formation of CaO.ZrO₂ when zirconium minerals were added,

and of 2CaO.Cr₂O₃ with chrome minerals.

A Study of the Reactions between Dolomite and Various Minerals. Part II.—X-Ray Examination of the Dolomite-B Steatite-A Series. J. R. Rait and H. J. Goldschmidt. (Second Report on Refractory) Materials, Iron and Steel Institute, 1942, Special Report No. 28, pp. 49-61). Fired dolomite-steatite mixtures containing initially from 0 to 15% of steatite and two commercial dolomite bricks have been submitted to X-ray analysis using a Debye-Scherrer camera. The relative intensities of characteristic lines have been measured photometrically. Qualitatively and quantitatively, within the limits of accuracy of the method, the results for the mineralogical constitution of the minerals of the sinters are in complete accord with those deduced in Part I. on the basis of determinations of free lime and consideration of the appropriate thermal equilibrium diagrams. For the particular dolomite and steatite investigated, the proportion of free lime present in the fired mixes decreased to nil as the initial steatite content increased to between 8% and 10%, at which content there was the maximum production of 3CaO.SiO2. Further addition of steatite resulted in a decrease of the amount of this constituent and a corresponding increase in the proportion of ·2CaO.SiO₂. The magnesia was present in almost constant amount as uncombined periclase.

A Study of the Reactions between Dolomite and Various Minerals. Part III.—Further X-Ray Examinations. J. R. Rait and H. J. Goldschmidt. (Second Report on Refractory Materials, Iron and Steel Institute, 1942, Special Report No. 28, pp. 63-90). In Part I. the mineralogical constitution of a number of clinkers, prepared by calcining mixtures of dolomite and various proportions of four different steatites, flint, serpentine, olivine, bentonite, china clay, alumina and ferric oxide were deduced from a consideration of the free lime contents, hydration curves and of the appropriate thermal equilibrium diagrams. The clinkers have now been submitted to X-ray analysis using a Debye-Scherrer camera. The results are in complete accord with the constitutions previously assigned, and

confirm the assumptions made regarding certain of the relevant four- and five-component systems. The evidence indicates a close approach to chemical equilibrium in the experimental clinkers and in commercial dolomite products. The results of the X-ray analysis and the calculated mineralogical composition of three commercial

products are likewise in close agreement.

A Study of the Reactions between Dolomite and Various Minerals. Part IV.—X-Ray Examination of the Sinters Containing Zirconia.

J. R. Rait and H. J. Goldschmidt. (Second Report on Refractory Materials, Iron and Steel Institute, 1942, Special Report No. 28, pp. 91–99). Specimens of fired mixtures of dolomite with various proportions of zirconia, synthetic zircon, natural zircon and baddeleyite have been submitted to X-ray analysis by the Debye-Scherrer powder method. From the photographs obtained, conclusions regarding the constitutions of the sinters have been made which substantiate those made previously on the basis of determinations of uncombined lime, steam hydration indices and from a consideration of the available thermal equilibrium data. It is confirmed that calcium metazirconate is formed by the reaction of zirconia or zircon with the lime. Magnesia remains uncombined as periclase.

A Note on a Simple Partially Stabilised Dolomite Mixture. W. J. Rees. (Second Report on Refractory Materials, Iron and Steel Institute, 1942, Special Report No. 28, pp. 101-102). Some years ago the author examined the effect of additions of comparatively small proportions of clay and iron as stabilisers for dolomite and obtained promising results with a mixture of ground dolomite 95%, ball clay 2.5% and mill scale 2.5% (by weight). In the present note the author gives the results of some further experiments with this mixture. A quantity of the mixture was tempered with 10% of water containing a little sulphite lye. This was made into briquettes which, after drying, were burned at 1500° C. A number of the briquettes were crushed and made into test-pieces. The chemical analysis of the fired briquettes gave: CaO 52.05%, MgO 34·82%, Fe₂O₃ 5·08%, Al₂O₃ 3·41%, SiO₂ 4·30%, and loss on ignition 0.40%. The refractoriness-under-load, spalling resistance and resistance to corrosion by a basic open-hearth slag were very satisfactory and promising enough to warrant a trial on a larger scale than is possible in a laboratory. It appears that bricks made from this mixture are likely to have a better slag resistance and spalling resistance than bricks made from a dolomite which has been completely stabilised by the addition of silica, or a silicate such as serpentine, sufficient to convert the lime into the di- or tricalcium silicate.

The Influence of Working Conditions on the Durability of Blast-Furnace Linings. G. R. Rigby and A. T. Green. (Second Report on Refractory Materials, Iron and Steel Institute, 1942, Special Report No. 28, pp. 103–130). The conditions prevailing during a

blast-furnace campaign are first analysed. Collected data indicate the wide variations which have occurred in the stacks of different blast-furnaces due to segregation of the burden. Factors governing burden distribution are shown to have an important influence on the temperatures prevailing at the lining face. Abnormal conditions in the stack are considered to cause channelling in the lining in specific parts of the furnace. The reported investigations of the linings of blown-out furnaces are reviewed and data obtained from a number of recently blown-out furnaces are also incorporated. A summary is given of the laboratory investigations on such important aspects of refractory materials as carbon monoxide disintegration, alkali attack, and the action of blast-furnace slags. The properties which refractory materials for blast-furnaces should possess are considered in the section dealing with the choice of material for the lining. The final sections of the paper are devoted to a discussion of the influence of water cooling in the stack, the effect of insulation and the blowing-in of the furnace.

Temperature Gradients through Blast-Furnace Linings. Part I.— An Investigation of a Furnace Not Fitted with a Stack Cooling System. G. R. Rigby, H. Booth and A. T. Green. (Second Report on Refractory Materials, Iron and Steel Institute, 1942, Special Report No. 28, pp. 131-154). An attempt has been made to assess the rate at which the blast-furnace lining wears back by inserting thermocouples in five planes in the stack and bosh and taking continuous records of the temperatures. The results indicated the formation and subsequent removal of temporary scars in the bosh region. The temperature records in the stack have been correlated with variations in the flow of the blast through the stack due to burden changes. The computed furnace lines at the end of the campaign compare satisfactorily with the lines as actually measured. It is considered possible from such temperature data to obtain an estimate of the lines of the furnace at any particular time during the campaign. In an appendix the effect of segregation of the burden on the life of the lining is treated in a general manner.

Summary of other Published Work of the British Refractories Research Association of Interest to the Iron and Steel Industry. (Second Report on Refractory Materials, Iron and Steel Institute, 1942, Special Report No. 28, pp. 155–168). In addition to the papers on basic refractories reprinted in the present Report, the British Refractories Research Association has published some twenty other papers on the subject since the First Report was issued in 1939. A large proportion of these papers refers to dolomite products and these are dealt with first in the present summary. Work on the action of slags, vapours and gases on refractories is reviewed next. In conclusion brief references are made to work on the manufacture of carbon blocks for blast-furnace hearths, the feasibility of dry-press or tamping methods for making briquettes

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from foundry coke and gas-works pitch, the effects of electrolyte additions to clay-grog mixtures on the properties of refractory jointing cements, the stability of kyanite cements and high-tem perature insulating refractories.

Modern Hearth Refractory Practice. H. N. Barrett jun. (Blast Furnace and Steel Plant, 1941, vol. 29, Dec., pp. 1218–1220). An illustrated description is given of the design of open-hearth furnace bottoms made with a proprietory refractory material consisting of dead-burned clinker containing a high percentage of magnesia.

Insulating Fire Brick in Modern Furnace Construction. N. A. Humphrey. (Blast Furnace and Steel Plant, 1941, vol. 29, Dec., pp. 1197–1201). The author discusses the theory of the use of insulating bricks with and without a firebrick lining for furnaces under continuous and intermittent heat. Several series of graphs are presented showing the rates of heat transmission of insulated and uninsulated furnace walls during heating and cooling together with cost data which enable the initial costs and heat losses of walls of different thickness of different combinations of brick to be compared.

FUEL

(Continued from pp. 172 A-175 A)

The Flame Temperature of Gases. (Coke and Smokeless-Fuel Age, 1942, vol. 4, Feb., pp. 29–32). The theory of the flame temperature of gases with special reference to the effects of incomplete chemical reactions in the flame, radiation from the flame and the heat capacity of the products of combustion is discussed. Examples are also given of the effects of preheating the gas and air before combustion. The heating value of all rich gases, from blue watergas upwards, is very much the same where flame temperature is the dominating property. Where gases of lower grade, such as producer gas, are used, any disability which they possess can be amply made up by preheating both the air and gas.

The Gas Turbine in Iron and Steel Works. M. Schattschneider. (Iron and Steel Institute, 1942, Translation Series, No. 75). An English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, May 8, pp. 465–473. (See Journ. I. and S.I., 1941,

No. II., p. 64 A).

Carbonizing Properties and Petrographic Composition of No. 1-Bed Coal from Bell No. 1 Mine, Sturgis, Crittenden County, Ky., and the Effect of Blending this Coal with Pocahontas No. 3- and No. 4-Bed Coals. J. D. Davis, D. A. Reynolds, R. E. Brewer, G. C. Sprunk and L. D. Schmidt. (United States Bureau of Mines, 1941, Technical Paper No. 628).

Carbonizing Properties and Petrographic Composition of Powellton-Bed Coal from Elk Creek No. 1 Mine, Emmett, Logan County, 214 A FUEL.

W. Va., and the Effect of Blending this Coal with Pocahontas No. 3and No. 4-Bed Coals. J. D. Davis, D. A. Reynolds, G. C. Sprunk and C. R. Holmes. (United States Bureau of Mines, 1941, Technical

Paper No. 630).

A Study of Certain Indian Coals. E. R. Gee. (Records of the Geological Survey of India, 1941, vol. 75, Professional Paper No. 11). The author gives a brief review of the coal deposits of India and describes research work on the analyses and properties of several India coals which was carried out at the Imperial College of Science, London. The future possibilities of the coal industry of India are also dealt with.

The Effects of Heat and Pressure on the Sulphur Compounds in Coal. G. A. Smith. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1942, vol. 42, Dec., pp. 149–168). The author examined the behaviour of the different forms of sulphur in coal when heated at normal and at high pressures. The special apparatus for high-pressure experiments is described. Pyrites in coal decomposes on heating to form sulphide, organic sulphur and gaseous sulphur compounds. The sulphur distribution from pyritic decomposition becomes static and ceases to change after a certain definite time of heating. At temperatures below 500° C. it is possible for appreciable amounts of organic sulphur to be formed from pyrites, particularly in coking coals, without the production of sulphide which always occurs at or above 500° C. in accordance with the equation:

$FeS_2 = FeS + S.$

The maximum amount of organic sulphur is formed from pyrites at 500° C., both at normal and at high pressures. At all temperatures a small portion of the original pyrites remains undecomposed. Coking constituents play a more decisive rôle in influencing the sulphur distribution on heating than normal differences in volatile contents. At 500° C., and to a lesser extent at 600° C., these constituents inhibit the formation of sulphide and increase the organic sulphur under normal pressure. A good coke is produced from a non-coking coal by pressure at 500° C., but no inherent coking powers are created at lower temperatures, probably because of the lack of hydrogen. The formation of coke at 500° C., as compared with 550° C. found by other workers, is attributed to the use of higher pressures. The amount of volatile matter destroyed under pressure appears to be of the same order as that evolved from the coal under normal pressure at the same temperature.

The Various B.T.U. Values of a Coal. J. F. Barkley and L. R. Burdick. (United States Bureau of Mines, 1941, Dec., Information Circular No. 7193). The author explains the different ways of expressing and calculating the calorific value of a coal in British Thermal Units. The value is ordinarily expressed in B.Th.U. per lb. for the coal (a) as received, or as sampled, (b) moisture-free,

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or dry, (c) moisture- and ash-free, (d) without including the heating value of the sulphur in the coal, (e) dry and mineral-matter-free, and (f) moist and mineral-matter-free. If the moisture, ash and sulphur contents are known, any one of these values may be

calculated from any other.

The Evaluation of Fuels from the Thermal and Metallurgical Viewpoints as a Basis for their Economic Preparation. H. Bansen and E. Krebs. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, July, pp. 1–10). The authors explain methods of calculating the most economic manner of utilising coals of different ash content and calorific value. The method enables the maximum ash content to be determined above which it is no longer economic to use the coal for steam raising. Examples are given of the comparison of the heating value of a fuel with that of a "standard" fuel and the evaluation of coking coals and the economics of coal washing.

A Study of the Grindability of Coal and the Fineness of Pulverized Coal when Using the Lea-Nurse Air Permeability Method for Evaluating the Subsieve Fractions. J. B. Romer. (Proceedings of the American Society for Testing Materials, 1941, vol. 41, pp. 1152–1165). Methods now used for determining the particle size of pulverised coal and finished cement are briefly discussed and the Lea-Nurse permeability method of determining the specific surface area of a powdered sample is described and examples are given to show how data obtained by the Lea-Nurse method are applied to determine the grindability index of a coal.

Practical Experience in the Briquetting of Bituminous Coking Coal. J. Shanks. (Canadian Mining and Metallurgical Bulletin, 1942, Jan., pp. 15–26). A description is given of the plant and process used at a colliery in Alberta for briquetting a bituminous coking coal. The colliery in question produces a high percentage of fines and these form the raw material for the briquettes. About 10% of the briquettes are mixed with ordinary coal and the mixture

is a satisfactory fuel for locomotives.

Methods of Increasing Production of Existing Steel Plant Equipment. 1. Coke Plants. W. T. Brown. (Iron and Steel Engineer, 1942, vol. 19, Jan., pp. 51–54). In considering methods of improving the quality of blast-furnace coke the author suggests the installation of vibrating screens between the coke bins and the skip hoist of the blast-furnace so as to ensure that the coke charged is fairly uniform in size. The present capacity of cokeoven plants might be increased by using a small proportion of low-volatile coal in the mix, by pushing the coke while it still contains 1·0–1·5% of volatile matter, and by treating the crushed wet coking coal with about 1 gal. of a naphthenic petroleum oil per ton of coal to increase its bulk density.

Ammonium Sulphate Production—Low-Differential, Large-Crystal Ammonium Sulphate Process. W. Tiddy. (Eastern States Blast Furnace and Coke Oven Association: Blast Furnace and 216 A FUEL.

Steel Plant, 1941, vol. 29, Dec., pp. 1213–1217, 1243). The author describes a coke-oven by-product plant for producing ammonium sulphate of improved quality which compares favourably with the synthetically produced product. The new process involves the use of a scrubber for the recovery of ammonia from coke-oven gas in which a circulating stream of ammonium sulphate containing free sulphuric acid is passed in countercurrent contact with the gas for recovery of ammonia. This stream is then pumped into a vaporising zone where it is cooled by evaporation to a supersaturated condition. The resultant solution then passes through a bed of crystals and deposits more crystals on it. The mother-liquor produced in this system flows to the mixing tank where water and sulphuric acid are added as required by the process.

British Standard Test Coke for Gas Producers. (British Standards Institution, No. 995—1942). This British Standard test code applies to gas producers of all descriptions except slagging producers and portable producers. It is deemed to contain all the necessary data for the determination of the performance of the plant together with a full explanation as to how the necessary observations should

be made.

Present Position and Development during the last Ten Years of Blast-Furnace-Gas Cleaning. K. Guthmann. (Stahl und Eisen, 1941, vol. 61, Sept. 18, pp. 865-870; Sept. 25, pp. 883-891). The author reviews the development of blast-furnace-gas cleaning plant, describing many different types and discussing their economy. The development is characterised by the introduction of cyclones to remove the coarse dust with the object of lightening the load on the fine dust plant, as well as by the further improvements in electric gas-cleaning methods. The ever increasing demand for dry, high-purity, gas at about 20-25° C. with a dust content not exceeding 5-10 mg. per cu. m. at N.T.P. as fuel for blast-furnace stoves, boilers, coke-ovens and metallurgical furnaces has stimulated the construction of plants operating wet processes, such as wet electric filters and two-stage electric filters which have proved to be very reliable and operate at low cost. The purification of effluents in order to reduce the amount of make-up water required has also received great attention.

New Electric Gas Cleaning Plant at the Oberscheld Blast-Furnaces of the Buderus'sche Eisenwerke. F. Eichler. (Stahl und Eisen, 1941, vol. 61, Oct. 16, pp. 945–949). The author presents an illustrated description of the two-stage electric-precipitation gas-cleaning plant for removing the dust from the blast-furnace gas at the Buderus'sche Eisenwerke. This plant is of the Siemens-Lurgi-Cottrell type and it was put in commission in 1940. It consists of three units connected in parallel each with a capacity of 13,300 cu. ft. of gas at N.T.P. per hr. The gas, carrying 5–8 g. of dust per cu. m. at a temperature of 150–300° C., first passes through the precooler which brings the temperature down to 60–80° C. It

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is then fed between the electrodes of the dry filter; these electrodes are kept free from dust by an electrically driven rapping device which keeps them in constant vibration. The dust falls to the bottom of the cone-shaped filter body from which it is discharged by an impeller on to a conveyor belt. The gas, now containing an average of about $0.56~\rm g$. per cu. m. of dust, is at about 70° C. and it next passes through a second cooler which reduces the temperature to $15-25^{\circ}$ C. The final cleaning is done in a wet electric-precipitation filter which reduces the dust content to about $0.003~\rm g$. per cu. m. The difficulties experienced in the first ten-months' working and the methods of overcoming them are discussed. Some

process and cost data are also presented.

The Construction and Operation of a Two-Stage Electric Cleaning Plant for Blast-Furnace Gas. W. Rabe. (Stahl und Eisen, 1941, vol. 61, Nov. 27, pp. 1079–1083). The author describes an electric gas-cleaning plant which was put in at the Ilsede Hütte in 1939. To save ground space the whole plant had to be carried on a ferroconcrete platform 25 ft. above ground-level; the total pressure drop on the gas system had not to exceed 120 mm, of water, and as the works' water supply was very limited the amount of makeup water for the new plant had to be kept as low as possible. The plant consists of three units in parallel each with a capacity of 60,000 cu. m. of gas at N.T.P. per hr. Each unit has a precooler 4.30 m. in dia. and 18 m. high, an electric precipitator, an electric dry filter, a final cooler and an electric wet filter with the necessary pumps, conveyors, sludge hoppers and wagons. The total current consumption of the plant amounts to 1.25 kWh. per 1000 cu. m. at N.T.P. The average figures for the dust removed from the gas in the first seven-months' working reveal that the amount in the raw gas was 3.481 g. per cu. m. at N.T.P. and that 99.8% of this was removed. A diagram of the plant is presented together with tables of operating data.

Coke Oven and Blast Furnace Gas. Distribution, Control and Application Problems. W. B. Wright and T. F. Pearson. (Journal of the West of Scotland Iron and Steel Institute, 1941–42, vol. 49, Part II., pp. 23–38). The authors review some of the problems and existing data in connection with the distribution, control and application of by-product gases for iron and steel works use. In the first section the constitution of the gases, advantages of storage facilities, allocation to the various departments and measurement of gas flow are dealt with. In the second section the authors discuss the problems and difficulties experienced in the application of these gases to high-temperature furnaces, the possibilities of replacing producer gas by clean mixed gases and the requirements which are of prime importance for the successful application of

by-product gases.

PRODUCTION OF IRON

(Continued from pp. 175 A-176 A)

The Production of Pig Iron in the Electric Furnace. M. Kauchtschischwili. (Stahl und Eisen, 1941, vol. 61, Nov. 13, pp. 1033–1035). The author reviews recent developments in the electric smelting of iron ores and describes a 12,000 kVA. furnace erected in Italy in 1940. A feature of this furnace is that the clamping and feeding mechanism for the three electrodes is built into the furnace roof instead of being above it; this enables the length of the electrodes to be reduced by 1–1·5 m. In the daytime a maximum current of 11,000 kW. could be applied, whilst at night this was reduced to 6000 kW. and the furnace could not be tapped at night. The current consumption in the first three-months' campaign was 2790 kWh. per ton of pig iron produced using for reduction a mixture of 70% anthracite high in ash and 30% gas coke.

Methods of Increasing Production of Existing Steel Plant Equipment. 2. Blast Furnaces. L. E. Riddle. (Iron and Steel Engineer, 1942, vol. 19, Jan., pp. 55–57). The author suggests methods of improving the production of pig iron in the Pittsburgh district. Furnaces should be blown with at least 150 cu. ft. of air per min. per sq. ft. of hearth area, and where the coke is made from mixtures containing about 50% of low-volatile coal the rate should be not less than 160 cu. ft. per min. The stove capacity should be equivalent to 500 sq. ft. of heating surface per ton (2000 lb.) of the rated iron capacity; the heating surface of stoves can be increased by the installation of inserts. If the pig-iron consumer will permit the maximum amount of sulphur in the hot metal to be raised from 0.030% to 0.035–0.040% the production of the blast-furnaces could be increased.

Precautions against Frost in Ironworks. K. Guthmann. (Stahl und Eisen, 1941, vol. 61, Dec. 18, pp. 1149–1152). The author reports on some of the experiences of German ironworks in combating the difficulties caused by the frost in the winter of 1940 and describes some methods of dealing with frozen wagons of ore, coking coal and limestone, with frozen pipe lines, crane rails and

coolers for gas-cleaning plant.

Cleaning of Blast Furnace Cooling Coils Increases Furnace Life. K. I. Robinson. (Blast Furnace and Steel Plant, 1941, vol. 29, Dec., pp. 1207–1209). The author describes a mechanical appliance for cleaning scale and deposit from the inside of the cooling coils in the refractory lining of blast-furnace hearths. The appliance consists essentially of a number of sizes of spring steel cables which are inserted in the tubes and rotated at about 1200 r.p.m. by an electric motor.

Science of Slags as a Basis of Ferrous Metallurgy. F. Körber and W. Oelsen. (Iron and Steel Institute, 1942, Translation Series, No. 74). An English translation of a paper which appeared in Stahl und Eisen, 1940, vol. 60, Oct. 16, pp. 921–929; Oct. 24,

pp. 948-955. (See p. 7 A).

Contribution on the Metallurgy of Manganese. G. Volkert. (Stahl und Eisen, 1941, vol. 61, Oct. 9, pp. 938–940). The author discusses methods of producing high-carbon and low-carbon ferromanganese. If the alloys used as raw materials are high in carbon the carbon cannot be got rid of, for, when treated with slags containing oxides, the silicon, not the carbon, is oxidised. Data on the carbon/silicon ratio with different quantities of iron present are given, and three electric-furnace methods of producing silicomanganese as a raw material for the production of low-carbon ferro-manganese are described.

Vacuum Aids Formation of Powder Metallurgical Compacts. C. Hardy. (Steel, 1942, vol. 110, Jan. 19, pp. 84–86). The author points out some of the advantages gained by applying a vacuum to the system when feeding metal powders into dies for producing parts by the powder-metallurgy process. The powders flow much more readily and there is a great saving in the power required for compression when most of the entrained air has been exhausted. Some data on the rates of flow of powders of different size through an ½-in.-dia, orifice at atmospheric pressure and under vacuum are

presented

The Scientific and Technical Principles of Powder Metallurgy and its Sphere of Application. W. Dawihl. (Stahl und Eisen, 1941, vol. 61, Oct. 2, pp. 909-919). The author reviews present knowledge on the mechanism of the powder-metallurgy process. The grain size and the ability of the grains to change shape are the principal factors affecting the porosity, strength, hardness and electrica properties of parts made by the process of powder metallurgy, and these two factors are in turn dependent on the previous history and method of preparing the metal powders. In the sintering of metal powder mixtures at temperatures above the point at which melting commences, the particles of the higher-melting-point metal form a framework which is filled with the lower-melting-point metal. This framework is fundamentally similar to that formed by the sintering of a powder consisting of one metal only. If, however, the sintering temperature of mixed metal powders is below the melting point of the metal with the lowest melting point, as in dry sintering, then a framework made up of grains of the different metals is formed and this may cause the product to have properties fundamentally different from those of parts sintered at higher

Progress in the Production of Magnets from Sintered Iron-Nickel-Aluminium Alloys. W. Hotop. (Stahl und Eisen, 1941, vol. 61, Dec. 4, pp. 1105-1109). The author discusses the advantages

gained by using the powder-metallurgy process to make permanent magnets, the difficulties arising owing to the oxide-forming properties of aluminium powder and how these have been overcome. For making permanent magnets of iron-aluminium-nickel alloys it is recommended that a powder should first be prepared from an alloy of 48% to 53% of aluminium with the balance iron, which should form up to 30% of the mixture to be sintered, the balance consisting of iron and nickel powders to give a final composition of about iron 60%, nickel 27% and aluminium 13%. If the sintering temperature is 1300° C. the initial iron-aluminium alloy will melt before this is reached and will diffuse throughout the mass, thus producing a homogeneous sintered product. Tests of the effect of different pressures applied at the sintering temperature on the density and magnetic properties of the product showed that there was practically no change. The following are suitable conditions for producing sintered permanent magnets: (a) An electrically heated furnace with molybdenum elements, supplied with a protective atmosphere of hydrogen; (b) a sintering temperature of 1200° to 1330° C.; and (c) a sintering time of $1\frac{1}{2}$ to 4 hr.

FOUNDRY PRACTICE

(Continued from pp. 176 A-178 A)

Recent Developments in Cast Metals. C. H. Lorig. (National Founders' Association: Foundry, 1942, vol. 70, Jan., pp. 69, 159–165). In reviewing recent technical improvements in foundry practice the author discusses the following points: (1) A control device which makes simultaneous records of the volume of air entering the cupola and the amount of carbon dioxide in the flue gases, and automatically regulates the former so as to maintain the latter at the predetermined amount; (2) the control of the moisture in the air; (3) the use of one synthetic moulding sand for a variety of castings; (4) the addition of 2 g. tellurium with 2 oz. of graphite per 1000 lb. of metal for making chilled castings; (5) the preparation of short-cycle malleable iron which is fully malleablised in less than 15 hr.; (6) the development of low-alloy highstrength cast steels; and (7) the centrifugal casting of steel gear blanks.

Wasteful Foundry Practice. P. R. Ramp. (Iron Age, 1942, vol. 149, Jan. 15, pp. 34–36). The author makes recommendations with the object of saving metal and fuel in foundries. He stresses the necessity of having a good hot bed in the cupola and gives some examples of incorrect and correct moulding practice which show how the size of risers can be considerably reduced.

Melting Quality Iron in the Cupola. H. S. Austin. (American Foundrymen's Association: Foundry, 1941, vol. 69, Nov., pp.

59, 139-143; Dec., pp. 59-61, 140-144). The author describes in detail the cupolas and cupola practice at the works of the Buick Motor Division where there is a battery of six cupolas 8 ft. in outside dia. and 67 ft. high producing iron for casting all types of

automobile parts.

Improving Cupola Performance. D. J. Reese. (Foundry, 1942, vol. 70, Jan., pp. 62-65, 151-155). The author makes the following recommendations on the improvement of cupola performance: (1) In calculating the composition of the charge, the amount of coke per square foot of hearth should be decided first; (2) the weight of the metal charged should be calculated in relation to the weight of coke having regard to the proportion of steel; (3) careful weighing is necessary—as a rule insufficient care is taken in checking the tare weights of wheelbarrows and charging buckets; (4) the maximum linear dimensions of materials in the iron charge should not exceed 30% of the cupola diameter and the size of the coke should be about one-twelfth of the cupola diameter; (5) with small cupolas the limestone should be in pieces of $\frac{3}{4}$ in. to 1 in.; (6) charge a quarter of the total bed coke at a time; (7) put in the initial limestone when three-quarters of the bed coke has been charged: (8) when the coke-bed height is at the desired level charge with the least possible delay and put the blast on immediately; and (9) keep careful check of the blast pressure throughout the operation and of the metal temperature when tapping.

The Disposal of Molten Cupola Slag. J. Hird. (Foundry Trade Journal, 1942, vol. 66, Feb. 26, p. 136). A brief description is given of a novel method of dealing with cupola slag which makes it easy to handle and keeps the foundry floor clear. It consists of running the slag down a spout into a series of troughs similar to those used on pig-casting machines at blast-furnaces. The troughs are mounted on a frictionless bogey which is pulled along under the slag spout as each trough is filled with slag. The slag sets in 10 to 15 min., and the trough is then turned over, the pig of slag falling on the floor. The troughs are then returned to their original positions and are ready for the next slagging out. There is sufficient room under the troughs for a considerable number of pigs which

can be left until the cast is over.

The Manufacture of Malleable Castings by the Whiteheart Process. A. E. Davies. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 66, Mar. 16, pp. 167–169). The author describes the process of making whiteheart malleable iron castings with special reference to the moulding and pouring technique and to the mixing of the ore in which the castings are packed for the malleablising treatment.

The Making of Patterns and Castings for Rolling-Mill Looping Guides. K. Hoffmann. (Giesserei, 1941, vol. 28, Sept. 19, pp. 401-404). The author describes the technique to be followed in making patterns for looping guides for three-high stands. These

are used principally for guiding a bar leaving an oval pass between the top and centre rolls to enter a square pass between the centre

and bottom rolls or vice versa.

Gating and Moulding Malleable Cast Iron. C. C. Lawson. (American Foundrymen's Association: Foundry, 1940, vol. 70, Jan., pp. 70–71, 156–158). The author describes and illustrates a number of malleable iron castings for the automobile industry and explains how small alterations in the design enabled shrinkage troubles to be avoided.

The Running and Risering of Iron Castings. E. M. Currie. (Institute of British Foundrymen: Foundry Trade Journal, 1942, vol. 66, Mar. 12, pp. 163–164). A brief report is presented of the author's paper on gating problems which was illustrated with ciné films; these films showed the effects of different basin shapes and methods of trapping slag and dirt.

Describes Causes and Remedies for Blows in Gray Iron Castings. W. A. Hambley. (American Foundryman, 1941, vol. 3, Dec., pp. 7-8). The author defines the defects in castings caused by gas; these include blows, gas holes, pin holes and blisters. The conditions giving rise to these defects are listed in tabular form.

Describes Causes and Remedies for Problems on Inclusions in Gray Iron Casting Work. W. B. McFerrin. (American Foundryman, 1942, vol. 4, Feb., pp. 2–3). The author defines terms used for casting defects caused by inclusions of sand, slag &c. and classifies the possible origin of the defects under such headings as design, moulding sand, cores, moulding practice, cupola operation.

Gas Heating in the Foundry. W. Callenberg. (Giesserei, 1941, vol. 28, July 11, pp. 311–313). The author discusses the relative merits of long-distance gas, producer gas, coke-oven gas and blast-furnace gas for the heating of core ovens and other purposes in

the foundry.

Recent Information on the Drying of Moulds and Cores. W. Callenberg. (Giesserei, 1941, vol. 28, Sept. 19, pp. 397-401). The author studied the theory and practice of drying moulds and cores. The results of some distillation tests on core-binder oils in which the properties of the distillates at different temperatures up to 300° C. were studied, are presented. From these it is concluded that all the fractions except the last are simply evaporation products because they showed no change when air was passed through them, whereas the last fraction became thicker when treated with The attachment of the binder to the sand is made up of four parts: (1) Adhesion of the binder on the surface of the individual sand grains; (2) capillary attraction between the sand grains; (3) the liquid cell content—this applies only to absorbed water, as in clay; and (4) liquid held in colloidal material. The "drying potential" is defined as the difference between the drying tendency, as determined by temperature and saturation, and the capillary attraction of the liquid. The factors which determine this and the rate of drying required are the size and type of the sand grains and the quantity and composition of the binder. The selection of a core binder must therefore be related to the type of sand, the size and shape of the core and the core strength desired, and the drying temperature and time must be related to the proportion of binder mixed with the core material. It is recommended that drying ovens be divided into compartments so that cores requiring a short drying time can be removed without interfering with those requiring a longer time, as it is of course wasteful to keep a whole batch of cores in the oven for the time and at the temperature necessary to dry the largest one.

Fundamentals of Ventilation in the Foundry Industry. H. Opitz. (Giesserei, 1941, vol. 28, Aug. 22, pp. 373-376). The author examines the causes of bad ventilation in foundries and the sources of dust in the atmosphere and discusses the design of suitable exhausting systems including special units for sand-blast and cleaning departments and for fumes from furnaces and casting pits, as

well as larger units for general ventilation.

Turret Lathe Castings must be Perfect. P. Dwyer. (Foundry, 1942, vol. 10, Jan., pp. 58-60, 148-150). The author describes the layout and moulding procedure at a large United States foundry making beds and parts for turret lathes and machine tools. Details of experiments by Dost to determine a suitable quality of iron for this purpose are given. (See Journ. I. and S.I., 1940, No. II., p. 96 A).

Cast Bomb Shells in Canadian Plant. P. Dwyer. (Foundry, 1941, vol. 69, Dec., pp. 50-53, 133-136; 1942, vol. 70, Jan., pp. 64-66, 134-137). The author describes the plant and processes at a large Canadian steel foundry manufacturing cast steel bomb cases.

Handling Materials in Iron and Steel Foundry. F. A. Westbrook. (Steel, 1942, vol. 110, Jan. 19, pp. 80-83). The author describes the layout of cranes and conveyors at an American iron and steel

foundry producing eastings up to 10 tons.

Measuring the Fluidity of Cast Steel. H. F. Taylor and E. A. Rominski. (American Foundryman, 1942, vol. 4, Feb., pp. 12-14). The authors describe a spiral fluidity test for cast steel which has been successfully used at a United States Navy steel foundry.

Accidents Due to Electric Current in Foundries and the Lessons to be Learnt from them. G. Zweiling. (Giesserei, 1941, vol. 28, Oct. 3, pp. 419-423).

PRODUCTION OF STEEL

(Continued from pp. 178 A-181 A)

Developments in the Iron and Steel Industry during 1941. W. H. Burr. (Iron and Steel Engineer, 1942, vol. 19, Jan., pp. 26-50). The author reviews progress in the construction and operation of iron and steel making and processing plant in the United States

during 1941.

Kembla Works New Electric Steel Plant. (B. H. P. Review, 1941, vol. 19, Dec., pp. 14–15). A description is given of a 10-ton Héroult electric furnace recently put in commission at the Kembla Works of Australian Iron and Steel Ltd. The bottom of the furnace has a burnt-in monolithic lining made of a mixture of 10% crushed open-hearth slag and 90% crushed magnesite. Three 12-in.-dia. graphite electrodes pass through the roof. For charging, the furnace roof is lifted and swung by means of a carrying trolley running on a circular track to a position approximately 90° from the normal. For transferring ingots to the forge shop a bogie is used which has sand trays permanently fixed on it; the ingot is laid on a tray and completely enclosed with a steel cover insulated with 3 in. of slag wool.

Brazilian Steel Plant Operates on Former Jungle Site. J. H. Drumm jun. (Brazilian Business: Steel, 1942, vol. 110, Jan. 19, pp. 56–57, 83). A brief description is given of the history of the erection of the iron and steel works of the Companhia Siderurgica Belgo-Mineira in the state of Minas Geraes, Brazil. At the Sabara Works there are two blast-furnaces, three basic open-hearth furnaces and a merchant mill; and at the Monlevade Works there are two blast-furnaces, two 35-ton open-hearth furnaces, a blooming mill and a rod and wire mill.

Lifting Magnets for the Steel Industry. H. L. Wilcox. (Steel, 1942, vol. 110, Jan. 26, pp. 82–86). The author discusses the design, control and operation of lifting magnets for various purposes in steelworks.

On the Theory of the Bessemer Process. T. Kootz. (Stahl und Eisen, 1941, vol. 61, Nov. 20, pp. 1053-1064). The author discusses the sequence of reactions taking place in a Bessemer converter and endeavours to establish a relation between this and the properties of the steel produced. The paper deals with the theoretical aspects of the work described in an earlier publication by Eichholz, Behrendt and Kootz (see Journ. I. and S.I., 1940, No. I., p. 182 A). changes in the oxidation process as the air passes from the bottom to the surface of the melt were examined. In spite of the rapid movement of the bath most of the added lime remained in the upper portion. The refining reactions took place in two stages; the iron and its companion elements silicon, manganese, vanadium and phosphorus formed oxides which could be regarded as the first products of combustion; these oxides then reacted with the lime and formed the slag proper. Calculations of the progress of the oxidation of mixtures of several elements for assumed ideal conditions are made and the results are shown by curves which illustrate the effect of different concentrations of oxides on the course of the reaction. An investigation of stableisen melts showed how the manganese oxidation reaction changed with temperature. The delay in the commencement of dephosphorisation was due to the fact that during decarburisation the slag layer surrounding the lime solidified and prevented the lime from coming in contact with the phosphorus; when all the carbon was oxidised, this solid skin dissolved and dephosphorisation then took place. Extending the blowing time caused the reactions to approach more nearly to this theoretical concept. The influence of the sulphur, oxygen and nitrogen reactions on the properties of the finished steel were studied. The degree of desulphurisation depended not only on the basisity of the slag and the temperature at the end of the process, but also on the duration of the blow; the shorter the blowing time the less sulphur was reabsorbed by the metal from the slag. The manganese content of the molten pig iron had a very restrictive effect on the slagging of the iron and, for equal iron contents in the final slag, the amount of oxygen in the steel increased with decreasing amounts of manganese in the pig iron. The nitrogen content of the finished steel increased slightly with increasing blowing time, but it was also dependent on the temperature of the melt and the partial pressure of the nitrogen in the blast.

Metallurgical Investigations on the Conversion of Basic Bessemer Pig Iron. P. E. Hardt. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, Sept., pp. 119-124). The author studied the effects of the following factors on the basic Bessemer process: (1) The type of mixer; (2) the amount and condition of the pig iron added to the converter, i.e., composition, temperature and viscosity; (3) the state of the converter, especially the number of melts blown per lining, the age of the third bottom, the length of the bottom, the number of open and blind tuyères and the positions of the latter, and the width of the mouth; and (4) the converter practice, i.e., the quantity and quality of the lime and scrap charged and the time of the addition of the latter, the pressure of the blast and the size of the blast mains. The investigation led to the conclusion that those qualities of basic Bessemer pig iron which cannot be converted easily are not completely homogeneous in the liquid state. Nonuniform distribution of the cementite, non-metallic inclusions &c., may lead to irregularities in the reactions and consequently to excessive ejects.

Methods of Increasing Production of Existing Steel Plant Equipment. 4. Bessemer and Duplexing. L. P. Lias. (Iron and Steel Engineer, 1942, vol. 19, Jan., pp. 60–63). In considering means of increasing the production of Bessemer steel the author presents and discusses curves which show: (a) How the installation of equipment for photo-electric recording of the converter flame temperature improved the uniformity of the quality of the steel; (b) the relation between the duration of the after-blow and the rejections due-to surface and internal defects; (c) how the time between casting and charging the soaking pits affected the soaking-pit time; and

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(d) the effect of low finishing temperature on the number of rejections

at the chipping bed.

Russian Open-Hearth Furnace Design. D. W. Rudorff. (Metallurgia, 1941, vol. 25, Dec., pp. 37–40). The author describes two new 220-ton open-hearth furnaces at the Zaporozhstal Works in the U.S.S.R. The hearth measures 46 ft. × 15 ft. 9 in. The bottom is 41·4 in. thick at the centre, this being made up of fused magnesite 9·1 in., magnesite brick 20·7 in., firebrick 7·1 in. and insulation material 4·5 in. These furnaces follow in the main the layout described by McDowell (see Journ. I. and S.I., 1940, No. I., p. 2 A) but owing to the type of door the slope of the roof arch is very steep with a rise of 1 in 5·5. Venturi type ports are employed, the design of which follows experience at other Russian works. Slag pocket dimensions are based on an estimate of 12·1 lb. of collected slag per ton of steel. The surface area of the checkerwork is related to the heat release in the furnace, 6154 and 4907 cu. ft. being provided in the air and gas chambers respectively.

Methods of Increasing Production of Existing Steel Plant Equipment. 3. Open Hearths. F. C. Swartz. (Iron and Steel Engineer. 1942, vol. 19, Jan., pp. 57-60). The author considers three classes of improvements which will increase the production of open-hearth furnaces, namely, low-cost, moderate-cost and high-cost improvements which can be effected very quickly, in a short time and in twelve to eighteen months respectively. Low-cost improvements include the reporting and study of delays, changes in port design and checkerwork, careful planning of heats, and the use of quicksetting bottom refractories. Under moderate-cost, short-time improvements come: the use of flue blowers in the spaces under the checkerwork, larger charging boxes, machines for fettling furnace bottoms and radiation pyrometers immersed in the bath. High-cost major improvements include: increasing the hearth area, the use of welded ladles, an adequate supply of charging boxes and cars, having sufficient cranes for hot metal, and charging machines to enable the furnaces to be charged as rapidly as possible.

The Development of the Open-Hearth Process at Witkowitz. A. Rotter. (Stahl und Eisen, 1941, vol. 61, Oct. 9, pp. 929–937; Oct. 16, pp. 949–956). The author gives details of the extensions and developments which have taken place at the Witkowitz steelworks since the last description of the plant published in 1922. Cost statements for the years 1914 and 1936, and for 1938 and 1940 are presented which enable the costs of producing steel by the basic Bessemer and the hot-metal/ore processes to be compared. The fuel and refractory material consumptions of 130-, 180- and 250-ton Talbot tilting furnaces and of 60-ton fixed furnaces are also presented and discussed, and it is shown that the development of the hot-metal/ore process using large furnaces has proved very suitable for the raw materials used at Witkowitz.

The Temperature Distribution in the Liquid Steel in Various Steelmaking Furnaces. D. A. Oliver and T. Land. (Iron and Steel Institute, 1942, this Journal, Section I.). Temperature distributions in three dimensions in the liquid steel in different types and sizes of steelmaking furnaces are recorded in this paper. Measurements of temperature were made by the Schofield-Grace procedure, which proved to be well suited to the making of temperature surveys. The detailed observations are given in pictorial form and embrace 40- and 25-ton acid open-hearth furnaces, 12-ton. 3-ton and 30-ewt. basic electric arc furnaces, together with a small 100-lb. high-frequency furnace with a basic lining. The results are also summarised in a Table which shows the maximum observed variations in both the vertical and the horizontal directions corresponding to different stages in the melting processes. These variations lie between zero and 45° C. Very small differences from point to point were found in all types of furnace when the metal bath was on the boil, but larger temperature variations were built up during the finishing stages when the stirring action of escaping gases was negligibly small. Mechanical stirring by rabbling resulted in greater equalisation, and is recommended prior to an immersion reading when precise control is being exercised. Finally, reasons are given for concluding that, subject to a suitable position being chosen for measuring the temperature, the observed single value is likely to be representative of the mean temperature under normal conditions to within $\pm 10^{\circ}$ C., or to within $\pm 20^{\circ}$ C. under extreme conditions.

An Investigation of the Chemistry of the Basic Steelmaking Process. H. Schenck and W. Riess. (Iron and Steel Institute, 1942, Translation Series, No. 72). An English translation of a paper which appeared in Archiv für das Eisenhüttenwesen, 1936, vol. 9, June, pp. 589–600. (See Journ, I. and S.I., 1936, No. II.,

p. 113 A).

Silicon Monoxide. C. A. Zapffe and C. E. Sims. (Iron Age, 1942, vol. 149, Jan. 22, pp. 29–31; Jan. 29, pp. 34–38). The authors review the available information on the existence of silicon monoxide and refer to their own research at the Battelle Memorial Institute from which they deduce that silicon monoxide not only may exist at steelmaking temperatures, but it may be of great importance in the deoxidation process. It may be formed in liquid steel by the reduction of silica or by the oxidation of silicon. They consider the five principal equations for such reactions in the iron-oxygen-silicon-hydrogen system. Increasing temperature and decreasing oxygen pressure favour the formation of [SiO], consequently, as [FeO] diminishes, the total oxygen content of the steel may actually increase. Certain hitherto unexplained characteristics of slags and refractories may be due to silicon monoxide.

Ferrous Electric Melting Furnaces. R. W. Ruddle. (Australian Institute of Metals: Australasian Engineer, 1941, vol. 41, Dec. 8,

pp. 11–12). The author reviews the history of the development of electric furnaces for metallurgical purposes and describes induction furnaces, Héroult direct-arc furnaces and the Greaves-Etchells type of arc furnace. In the last-named furnace two phases of the three-phase low-tension current are conducted to their respective upper electrodes whilst the third phase is connected to the hearth. This system of connection is effected by a system of transformer ratios which is arranged to give a perfect balance when the upper electrodes are also in perfect balance. The current flowing through the hearth generates a considerable amount of heat immediately below the liquid metal in a most efficient manner. The weakness of the system is the care which must be given to the hearth to prevent burning through.

Increased Production from Existing Arc Melting Furnaces. G. O. Van Artsdalen. (Iron and Steel Engineer, 1942, vol. 19, Jan., pp. 78–80). The author describes how the use of a new plastic refractory material for an electric-furnace bottom reduced the time for burning in and preparing the bottom from 84 hr. to 9 hr. As much less of the new material was required the melting space was correspondingly increased. Some improvements in the electrical connections and control devices are also described.

Induction Heating in War Production. F. T. Chesnut. (Mechanical Engineering, 1941, vol. 63, Dec., pp. 861–864: Metals and Alloys, 1941, vol. 14, Dec., pp. 851–855). The author describes how high-frequency induction melting is applied to the making of steel for centrifugally casting guns, for heating shells for piercing and nosing operations and for the surface hardening of many parts used in armament manufacture.

Designs New Assembly to Prevent Running Stoppers. (Steel, 1942, vol. 110, Jan. 26, pp. 64, 105). A description is given of a stopper rod assembly for steel ladles which is designed to increase the life of the stopper head. The actual stopper head is of graphite secured to the rod by a metal bolt. In the improved design the ordinary refractory sleeve at the bottom of the rod is replaced by one having a skirt extension which surrounds most of the head. The higher insulating properties of the refractory extension as compared with the graphite offer additional protection to the bolt and the rod end.

Measuring the Degree of Undercooling in Ingots. H. Siegel. (Stahl und Eisen, 1941, vol. 61, Oct. 30, pp. 991–995). The author discusses the difficulties encountered in making temperature determinations of molten steel in ingot moulds sufficiently rapidly to determine the degree of undercooling at different positions in the mould. The Bioptix instrument was successfully used to determine the surface temperature of liquid steel from an acid electric furnace. In this case the average undercooling from ingot centre to wall was 40–45° C. The high degree of undercooling near the mould wall was at first thought to be due to errors in the temperature readings

but they were later found to be correct. The theory that undercooling can take place when a well-refined steel is teemed into ingot moulds was confirmed and it was also noted that a very hard steel did not undercool any more than a medium hard steel. Further, the supposition that if it were possible to increase the undercooling of high-carbon steels, the difficulties arising from their wide solidification range would be reduced, was found to be incorrect. A discussion of the degree of undercooling possible with top-poured and bottom-poured ingots leads to the conclusion that the maximum possible undercooling is obtained with the latter practice, whilst with the former undercooling is difficult but not impossible to obtain. The undercooling capacity of a steel is an inherent characteristic which makes it possible to pour the steel at a correspondingly lower temperature and thus to affect the primary structure obtained; for, if undercooling were an induced property, it would be impossible to produce a number of uniform ingots by bottom-pouring.

Cost Evaluation in Steelworks. A. Müller. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, Sept., pp. 155–162). Cost evaluation consists of the presentation of costs, their comparison, the determination of deviations from standard costs, and the analysis and explanation of these deviations. The author gives numerous examples of the application of cost evaluation in steelworks practice, with particular reference to the basic Bessemer and open-hearth

processes.

REHEATING FURNACES

(Continued from p. 14 A)

Increased Production from Existing Billet Heating Furnaces. W. N. Horko. (Iron and Steel Engineer, 1942, vol. 19, Jan., pp. 70–73). The author describes the alterations made to a coal-fired furnace 38 ft. long × 10 ft. wide for reheating billets. These alterations comprised: (1) Replacing the water-cooled skid pipes with solid rails of a heat-resisting alloy; (2) changing from a water-pressure-driven pusher to a self-contained oil-pressure unit; (3) firing with oil instead of coal; and (4) rebuilding 17 ft. of the furnace at the hot end with 9 in. of best quality firebrick backed up with 4 in. of insulating brick.

The Heating and Heat Treatment of Ordnance. I. W. M. Hepburn. (Steel, 1941, vol. 109, Sept. 15, pp. 72, 84, 86, 168, 169). In the first part of this series of articles the author discusses and describes various types of furnaces used in the United States for heating billets and bars prior to forging them into shells, gun barrels and gun mountings. These furnaces include those with rotating hearths with the burners placed tangentially, batch

furnaces with silicon-carbide muffles, and pusher furnaces.

Furnaces for Armament. Parts I., II., IV. and V. (Industrial Heating, 1941, vol. 8, Oct., pp. 1069–1080, 1112–1114, 1164–1170; Nov., pp. 1235–1240). Part I. of this series is introductory in character; in it the furnaces used in armament production are classified according to their purpose and some of the technical terms used are explained. In Part II. furnaces for heating billets for shell-forging are described. In Part III. details of the equipment for heating shell noses are given, and Parts IV. and V. are devoted to descriptions of furnaces for heat-treating finished shell bodies and for hardening the cores of armour-piercing bullets.

FORGING, STAMPING AND DRAWING

(Continued from pp. 181 A-183 A)

Wide Variety of Forgings Produced Economically at Kropp Forge Company. W. N. Robinson. (Heat Treating and Forging, 1942, vol. 28, Jan., pp. 21–26, 30–33, 43). An illustrated description is given of the plant and equipment of a Chicago firm which makes a wide variety of both light and heavy forgings. Particulars of billet-heating furnaces, boiler plant for the steam hammers, heat-treatment department and machine shop are also included

in the description.

New Shell Forging Machine. (Heat Treating and Forging, 1941, vol. 27, Dec., pp. 608–609, 620). An illustrated description is given of an automatic shell-forging machine capable of producing from 240 to 300 finished 90-mm. shell forgings per hr. from hot steel billets. The cavity is formed in three piercing and one drawing stages. The innovations on the machine include a rotary indexing die table, self-aligning punches and mandrel with automatic stripping, combination roller and ring dies for the final drawing, and automatic cooling and lubricating of the punches and mandrel between each operation.

Standards and Methods Used in the Forging Plant. J. Mueller. (Heat Treating and Forging, 1941, vol. 27, Dec., pp. 605–607, 626). The author explains the purpose of time study and motion analysis and how these are applied in an American works making large numbers of light forgings. Specimens of the standards record

cards and order cards used are reproduced.

Forgings in the War of Machines. W. Naujoks. (Heat Treating and Forging, 1942, vol. 28, Jan., pp. 19–20, 48). The author discusses some problems arising in the adaptation of forging machines and technique from peace-time to war-time production.

Drop Stamping Small Parts. H. Hutton. (Aircraft Engineering, 1941, vol. 13, Oct., pp. 294, 296). Some examples are given of washers, brackets and surgical instruments which can be rapidly

made by drop stamping using a hammer of only 1-3 cwt. Many such hammers are now idle in Birmingham and Sheffield and it is suggested that some of these could be quickly adapted for making aeroplane parts with a single simple die instead of employing presses

requiring intricate tools.

Swelling and Pulling Forces in the Drawing of Bars. W. Lueg and A. Pomp. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 16, pp. 293–308). The Swelling of Drawn Material after Passing through the Drawing Die. (Stahl und Eisen, 1941, vol. 61, Dec. 25, pp. 1169-1172). The authors describe a series of drawing tests on three steels of different carbon contents in which accurate determinations of the forces required and the difference between the die and the bar diameters were measured. The pulling force required increased with increasing degree of reduction, entrance angle of the die, deformation resistance of the steel and die diameter. The swelling (i.e., the difference between the diameters of the die and of the drawn bar) increased with increasing degrees of reduction with small entry angles, but decreased with large entry angles. The swelling was greater with steel dies than with dies of the special hard alloys, but the change in the die material did not alter the pulling force required. The swelling was unaffected by changes in drawing speed. For the first pass there is a straight-line relationship between the pulling force and the amount of swelling, the one increasing with the other, and this is independent of the amount of work-hardening. In the range of die-entry angles used in practice (14-20°), changes in this angle do not affect this relationship.

The History of Wire-Drawing. F. C. Thompson. (Metal Industry, 1942, vol. 60, Jan. 30, pp. 70–72). The author surveys the history of wire-drawing from the earliest times. It is known that rules were drawn up in 1270 for the regulation of the wire-drawers of Paris and a description of a drawing plate has been found in writings of an even earlier date. Water-power was applied to wire-drawing probably about 1491. Brief details are also given of the introduction of the continuous rod mill, the continuous drawing machine, patenting, wet-drawing and the use of diamond dies.

ROLLING-MILL PRACTICE

(Continued from pp. 183 A-184 A)

Commonwealth Steel Company's Special Steels Plant. F. M. Gaussen and C. H. Cooke. (B.H.P. Review, 1941, vol. 19, Dec., pp. 10-11). The authors describe the plant and procedure at the rolling mills of the Commonwealth Steel Co., Newcastle (N.S.W.). This plant is designed for rolling the special steels produced in the

electric furnaces previously described (see p. 53 A). The blooming mill is a 30-in., two-high, reversing stand driven by a 1250-h.p. motor. The bar mill comprises five stands with 12-in. rolls; three of the stands are three-high and there is one intermediate and one finishing stand, all driven by a 1000-h.p. motor. The rolling of high-speed tool steel is briefly described.

Operating Problems in Bar Mills. W. H. Bennett. (Iron and Steel Engineer, 1941, vol. 18, Dec., pp. 64-69). The author discusses problems in the selection of billets to roll bars of given length and diameter, the preparation of billets for rolling, the reheating furnaces, the rolling process, the cooling beds and the shearing and

inspection departments.

A New Armour-Plate Rolling Mill. F. Münker. (Stahl und Eisen, 1941, vol. 61, Dec. 4, pp. 1101–1105). The author describes and illustrates an armour-plate mill of German design built for a foreign country; the mill is capable of rolling slabs up to 165 tons. The principal unit is a four-high stand the working rolls of which are 1100 mm. in dia. with an effective length of 5200 mm. The backing rolls are 1600 mm. in dia. Owing to the ample supply of coal but insufficient supply of electricity at the works, the mill is driven by a 5-cylinder reversing steam engine developing 30,000

h.p. Increased Production from Existing Plate Mill Equipment. A. F. Franz. (Iron and Steel Engineer, 1942, vol. 19, Jan., pp. 74-77). The author describes methods by which the output of a plate mill has been improved during the last two years. An accurate record of all replaced parts is kept and whenever a replacement occurs too frequently the causes are analysed by the operating, maintenance and engineering departments. Each day breakage or replacement reports are made out by departmental superintendents. The electric crane for the storage yard was improved by designing contact shoes and rails which were not affected by snow and ice. Reheating furnaces were improved by increasing the hearth width, fitting new oil burners, connecting the water lines for cooling furnace doors with armoured flexible hose instead of swivel joints and by lining the doors with plastic material instead of refractory bricks. The mill gear-reduction units were rebored and fitted with oversize babbit metal bearings. The plate gauge indicators on the stands were redesigned and the mechanism for moving the middle roll of the three-high stand was improved.

Revolving Shears for Tube Strip. E. Kästel. (Stahl und Eisen, 1941, vol. 61, Oct. 2, pp. 920–922). The author describes and illustrates the layout of a shearing table with revolving shears for the cutting of tube strip into any desired lengths from 4.8 to 7.5 m.

Methods of Increasing Production of Existing Steel Plant Equipment. 5. Mill Equipment. J. Malborn. (Iron and Steel Engineer, 1942, vol. 19, Jan., pp. 63–66). The author points out that the production of plate mills and more especially of continuous wide

strip mills is not limited by the mill stands themselves but by the capacity of auxiliary machinery and by lack of space to handle greater tonnages. It is suggested that a shearing machine normally shearing plate up to $\frac{3}{16}$ in. thick could, with proper maintenance, cut $\frac{1}{4}$ in. plate. The production of mills could also be increased if consumers did some of the shearing themselves. Shipyards might carry a greater stock of larger plates out of which they could themselves shear plates of small size wanted in small quantities, for this is the type of order which slows up the output of a rolling mill.

PYROMETRY

(Continued from pp. 93 A-94 A)

Thermo-Electric Pyrometry. R. A. Dunkley. (Anstralian Institute of Metals: Australasian Engineer, 1941, vol. 41, Dec. 8, pp. 14–15, 17, 18, 20, 32, 34). The author explains the principles of temperature measurement by means of thermocouples, discusses the metals and alloys used for various temperature ranges and the instruments used for indicating and recording the temperatures, and describes how the temperature of molten steel is taken.

Recommended Method for Measuring the Temperature of Liquid Steel with an Optical Pyrometer. K. Tawara. (Tetsu to Hagane, 1941, vol. 27, June, pp. 369-372). (In Japanese). The author describes the calibration and application of a disappearing-filament

pyrometer for liquid steel temperature measurements.

HEAT TREATMENT

(Continued from pp. 184 A-186 A)

The Design and Operation of Heat-Treating Furnaces for Processing Steel Mill Products. R. J. Gumaer. (Industrial Heating, 1941, vol. 8, Sept., pp. 951-956, 968; Nov., pp. 1274-1278). The author discusses factors affecting the design of furnaces for heat-treating steel strip, sheet, tinplate, tube and wire, and describes some modern batch and continuous furnaces for these products. In the second part burner design, furnace-atmosphere control and the selection of heat-treatment equipment for various purposes are dealt with.

Furnaces for Production Heat-Treating. R. Legrand. (Machinist, 1942, vol. 85, Jan. 24, pp. 1027–1030; Feb. 14, pp. 1084–1086; Feb. 21, pp. 1131–1133; Mar. 21, pp. 1256–1259). The author presents illustrated descriptions of the following types

of heat-treatment furnaces: (1) Continuous roller-hearth and pusher furnaces; (2) suspension-conveyor and chain-belt-conveyor furnaces; (3) walking-beam furnaces for heavy plates; (4) semi-continuous basket pusher furnaces; (5) rotating horizontal and vertical cylindrical furnace; (6) car-bottom furnaces; and (7)

stationary furnaces with removable hoods.

Compact Furnace Equipment for Limited Production has Broad Application. W. F. Ross. (Heat Treating and Forging, 1942, vol. 28, Jan., pp. 35–38). The author describes and illustrates a rotating-hearth cylindrical heat-treatment furnace capable of heating 250 lb. of steel parts per hr. to 1550° F. This furnace can be used for either continuous or batch heat treatment. A mast on which a spider is mounted passes through the axis of the furnace and wedge-shaped pans of a heat-resisting alloy fit into the spaces between the arms of the spider. The pans are mounted on trunions and can be tipped from outside the furnace by a hooked bar so that the contents are discharged down a chute into the quenching bath.

Shell for British 75-mm. Guns. L. E. Blood. (Machinist, 1942, vol. 85, Mar. 14, Armament Section). An illustrated description is given of the heat-treatment and machining operations at an

American plant manufacturing 75 mm. shells.

Free-Convection Cooling of Mild Steel Bars and Rods—Graphical Time-Temperature Relations. J. Griswold and O. S. Jenkins. (Transactions of the American Society for Metals, 1941, vol. 29, Dec., pp. 1002–1012). The authors explain a method of calculating the time required to cool iron and steel bars from one given temperature to another by first making a number of graphical integrations for heat loss through simultaneous radiation and natural convection, and then correlating the results by a factor which takes

into account variations in the shape, size and radiation.

Effect of Carbon on the Diffusion of Some Elements in Steel. H. Cornelius and F. Bollenrath. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, Sept., pp. 145-152). The authors studied the diffusion between 1100° and 1150° C. of molybdenum, chromium, tungsten, vanadium, titanium, phosphorus, silicon, nickel, cobalt and boron in steels containing 0.05% to 1.3% of carbon. They heated steel specimens 8 mm, in dia, and 60 mm, long, surrounded by the finely powdered metals, the diffusion of which was to be studied, for 150-400 hr., at pressures of 1 to 4×10^{-4} mm. Hg. investigation led to the following conclusions: The diffusion of those elments which close the γ -field and are liable to form carbides in steel is greatly affected by the carbon content of the steel. A carbide film is formed, and the greater the stability of the carbide the more does this film impede the diffusion. The amount of titanium, for instance, which is taken up by high-carbon steels is, therefore, negligible. The carbide film is apparently not the sole factor affecting the diffusion, because those elements which close the y-field but do not form carbides in steel also diffuse less with

increasing carbon content, though to a smaller extent than do the carbide-forming elements. The carbon content has little effect on the diffusion of those elements which extend the γ -field and are not liable to carbide formation. Boron decreases the γ -field to a considerable extent, and, despite its liability to carbide formation, its diffusion is not much affected by the carbon content.

Oxyacetylene Flame Hardening. J. G. Magrath. (Machinist, 1942, vol. 85, Jan. 10, pp. 958–960; Jan. 24, pp. 1036–1038; Feb. 14, pp. 1087–1089; Feb. 21, pp. 1134–1136; Mar. 21, pp. 1260-1263). Continuation of a series of articles (see p. 144 A). In the eighth part the author discusses how the severity of the quench in the flame-hardening process can be controlled by adjusting the distance between the burner and the quenching jets, adjusting the temperature, pressure and quantity of the cooling medium and by changing the cooling medium. Some curves are presented showing the different degrees of hardness obtained after quenching steels with rising carbon and manganese contents using water and highand low-pressure air. In the ninth part some practical hints on methods of counteracting or preventing the distortion of flamehardened parts are given. In the tenth part descriptions are presented of specially shaped burner heads for flame-hardening gear teeth. The eleventh part contains descriptions of burner heads with special quenching fittings for hardening parts of unusual shape with details of the correct technique. The twelfth part deals with the flame-hardening of small and large flat surfaces such as the tips of valve stems, rail ends and plates.

Modern Design of Annealing Covers. L. Wilson. (Iron and Steel Engineer, 1941, vol. 18, Dec., pp. 71–75). The author describes recent developments in the design of portable bell gas-fired, electrically heated and direct-fired annealing furnaces. The improvements on which furnace makers are now concentrating include minor changes, moving the heat source from the outside of the inner cover to the inside where it will be in direct contact with the work and the design of equipment for strand or continuous annealing. The advantages and disadvantages of cast and fabricated radiant tubes are discussed. The use of a large number of vertical tubes instead of fewer tubes of longer length has the particular advantages of facilitating better temperature control and making it possible to service the tubes while the furnace is in operation. Some details are given of a firing-retort furnace in which the radiant tubes are within the inner cover but exhaust into the space between the inner and outer covers. Another very recent development is that of a tower-type furnace heated with vertical radiant tubes for the continuous annealing of steel strip.

Substitute High-Speed Steels. (Machinery, 1942, vol. 60, Feb. 19, pp. 108–109). Reference is made to a recent Iron and Steel Control Order prohibiting the manufacture of steel containing more than

6.5% of tungsten, and particulars are given of the correct forging, hardening, tempering and grinding treatments for two steels known as "Substitute 66" and "Substitute 94" respectively. The former corresponds closely to the standard 18%-tungsten high-speed steel. The composition of the two steels is:

	6	'Substitute 66''	"Substitute 94"
Molybdenum.	%	5.0- 6.0	8.5- 9.0
Tungsten. %	**********	5.5-6.5	3.5-4.5
		4.0-5.0	3.5-4.5
Vanadium. %		1.25-1.50	1.25 - 1.50

Trouble Shooting in Tool Hardening. R. C. Stewart. (Iron Age, 1942, vol. 149, Jan. 15, pp. 25–32). The author suggests a systematic procedure for toolmakers to adopt when studying the

cause of the premature failure of cutting tools.

Coarse-Grained Hardness Cracks in Tools of High-Speed Steel and their Prevention. O. Pattermann. (Stahl und Eisen, 1941, vol. 61, Dec. 25, pp. 1161–1168). The author describes the hardening of high-speed steel tools, particularly milling cutters, and discusses the conditions giving rise to hardness cracks in coarse-grained material. These causes include overheating, holding too long at the hardening temperature and too severe quenching. Recommendations for the hardening of high-speed steels with different

tungsten contents are made.

Methods of Tempering Spring Steel Prior to Rustproofing. P. M. Fisk and E. F. Pellowe. (Machinery, 1942, vol. 60, Mar. 5, pp. 156-158). The authors describe a heat-treatment technique with which limited equipment and unskilled labour could be employed for the tempering of springs which are subsequently rust-proofed by a wet method. The plant consists of a pre-heater, two salt pots, a cold water tank and a hot water tank. The first salt bath is heated by gas, the burnt gases being used for heating the pre-heater. The second bath for tempering is also gas-heated, but a fan for cooling the pot is provided. The hot washing tank is heated by steam injection. The springs are held in cages and are first lowered into the pre-heater to remove oil and to dry them. They are then transferred to the first salt bath and heated to about 795° C. After up to 7 min. immersion, the cage is moved as rapidly as possible to the second pot, the temperature of which depends upon the carbon content of the steel-in the present case the temperature is about 340° C. After holding long enough to complete the transformation of the austenite to bainite the parts are quenched in the cold water bath in which a slight explosion takes place causing the greater part of the solidified salt to fall off. Washing in hot water follows, which removes any remaining salt.

WELDING AND CUTTING

(Continued from pp. 186 A-188 A)

Automatic Arc Welding in Ship Construction. F. G. Outcalt and J. M. Keir. (Iron Age, 1942, vol. 149, Jan. 22, pp. 36-42). The authors describe some small and some very large welding equipment in American shipyards for the rapid automatic welding of plates up to 1½ in. thick by the Unionmelt process. (See Journ.

I. and S.I., 1939, No. I., p. 284 A).

Welding of Pressure Vessels, Tanks and Heat Exchangers. H. B. Schlosser. (Welding Journal, 1941, vol. 20, Dec., pp. 865-869). The author describes the general application of electric welding to the fabrication of pressure vessels and heat exchangers in accordance with the Codes of the American Society of Mechanical Engineers. Information is given on jigs and positioning equipment for large cylindrical vessels, how to deal with distortion and

the welding of a steel vessel lined with Monel metal.

Some Effects of Heating in and above the Critical Range, with Special Reference to Carbon, Manganese and Molybdenum Steels. H. Allsop and H. Bull. (Transactions of the Institute of Welding, 1942, vol. 5, Dec., pp. 32-40). The authors present tables and graphs relative to ageing, and to the effects of grain size, heattreatment temperature and cooling rates on the properties of carbon and low-alloy steels which illustrate what happens in the heat-affected zone of a weld. Although the properties of a welded joint can be controlled to a limited extent by the choice of suitable rods, the positioning of the successive runs &c., it is almost certain that there will be irregularity in hardness and composition across a weld. It is suggested that there is room for experimental work by the steelmaker to produce materials not possessing these undesirable features, or only having them to a slight degree.

Weldability. H. Lawrence. (Steel, 1942, vol. 110, Jan. 26, pp. 90-94). The author explains the application of the iron-carbon diagram and the S-curve for a given steel for the prediction of the

hardness of the heat-affected zone after welding.

Weldability—Cracks and Brittleness under External Load. Part I. Types of Cracks and Definitions of Weldability. Part II. Tests for Cracking under External Load: Bend Tests. Tests for Cracking under External Load—Impact and Tensile Tests. Part IV. Hardness and Microstructure. W. Spraragen and G. E. Claussen. (Welding Journal, 1941, vol. 20, Aug., pp. 346-S; Sept., pp. 369-S-401-S; Nov., pp. 522-S-551-S; Dec., pp. 561-S-589-S). In the first part of this review of the literature up to July, 1939, on the cracking of welded structures under external load the authors discuss the published information on failures of large welded structures which have occurred in practice and their probable cause. In the second part several kinds of bend test for demonstrating the ability of a weld to resist external load are described. In the third part impact and tensile tests for the same purpose are dealt with and results obtained in practice are discussed. The fourth part of the review covers the literature on the factors affecting the hardness of a welded joint, the relation of the hardness to the microstructure and strength properties, and

the interpretation of micrographs and hardness test results.

Oxy-Acetylene Machine Cutting of Two Alloy Steels used for Pressure Equipment. L. C. Percival. (Transactions of the Institute of Welding, 1942, vol. 5, Jan., pp. 3-15). Oxy-acetylene machine-cut specimens of steel plates 1 in. and 2 in. thick containing molybdenum 0.5%, and specimens of 2-in. plate of 2%nickel steel were examined by hardness, tensile and bend testing, as well as metallographically. The results of tests on machinetool prepared specimens were compared with those obtained on the above specimens. Bend tests indicated the good ductility of the flame-cut specimens, which were bent with the flame-cut face in tension, and were reported as having bent through 180° without cracking. This was incompatible with the hypereutectoid-steel and white-cast-iron types of microstructures found on the flamecut surfaces of the molybdenum steels, so a microscopical examination was made of specimens cut from the crown of the bend. This revealed that small cracks had occurred in the flame-cut surfaces during the bend tests, these cracks being confined to the surface showing the hypereutectoid-steel and white-cast-iron types of microstructures. In the same way, it was found that rough and serrated parts of flame-cut surfaces (due to a dirty nozzle during cutting) of the 2-in. 2%-nickel steel cracked during the bend tests, although the bends were reported as having bent through 180° without cracking. From the point of view of fatigue, the thin surface layer of white-cast-iron structure, formed on the surface of the 0.5%-molybdenum steels, would naturally raise doubts, but for all ordinary purposes there did not appear to be any serious loss of ductility. When such edges are welded, the very thin surface layer is of course completely embraced in the welded joint. Where welding is not required, the thin surface laver should be removed by grinding. The maximum thickness of the surface layer was 0.002 in.—a very small percentage of the total depth of microstructural alteration caused by the flame-cutting of the 0.5%molybdenum steels. The essentially austenitic, or the austeniticmartensitic structure of the layer formed on the 2%-nickel steels where the oxygen cuts were clean, is known to be due to an enrichment of the surface in carbon and nickel, and, when a proper cut is made, no crack normally occurs in bend testing.

Plate Cutting in Ship Construction. F. G. Outcalt and J. M. Keir. (American Welding Society: Iron Age, 1942, vol. 149, Jan. 15, pp. 38–41). The authors describe the latest technique for

oxy-acetylene cutting ship plates in preparation for welding. The most complicated edge to prepare is that having the top and bottom corners bevelled and the middle portion vertical. A machine is described and illustrated with which this can be done in one pass. It has three burners set in one head at the angles required to cut the three faces; the head also carries a small wheel which travels on the plate and keeps the burners the same distance from the steel even if the plate is curved or buckled.

PROPERTIES AND TESTS

(Continued from pp. 196 A-203 A)

Light Metals and Steel as Materials. E. H. Schulz. (Stahl und Eisen, 1941, vol. 61, Dec. 11, pp. 1121–1125). The author reviews and compares developments in the production and application of the light metals and of steel, and points out that no large-scale substitution of steel by aluminium alloys can be expected. For one thing it requires about 8 or 9 times as much power to produce a ton of aluminium as for a ton of steel. A consideration of the properties of the two classes of material shows that each has a large sphere of application on which the other cannot trespass.

Design and the Utilisation of Material. E. Lehr. (Stahl und Eisen, 1941, vol. 61, Oct. 23, pp. 965–975). The author refers to the fact that during the last ten years investigations of the strength of materials have had as their principal ultimate object the design of structures and parts of minimum mass capable of withstanding maximum loads. He then describes instruments and equipment of recent design for the accurate measurement of elongation under static and dynamic loads and of fatigue strength. A number of examples are then discussed which show how test data obtained by such equipment have been successfully applied to attain the object mentioned above. The examples include riveted structures, wheel seats on shafts, crankshafts, connecting rods and springs.

The Technical Cohesive Strength and Yield Strength of Metals. D. J. McAdam jun. (American Institute of Mining and Metallurgical Engineers, 1942, Technical Publication No. 1414). In a mathematical discussion the author considers the factors affecting the technical cohesive strength of metals (see Journ. I. and S.I., 1940, No. II., p. 222 A) with special reference to the effect of different values of the three principal stresses. The technical cohesive strength of a metal cannot be represented by a single stress value, but comprises an infinite number of stress values corresponding to the infinite number of possible combinations of the principal stresses. Plastic deformation increases the technical

cohesive strength continuously up to the point of fracture. The three-dimensional diagram representing the technical cohesive strength of a metal has a three-cornered contour in a plane perpendicular to the locus of polar-symmetric stresses, and tapers non-linearly to a point. The three-dimensional diagram representing the yield strength has a circular contour and tapers non-linearly to the same point. For a ductile metal, the diagram representing

vield strength is inside the other diagram.

Compression and Tension Tests of Structural Alloys. B. Johnston and F. Opila. (Proceedings of the American Society for Testing Materials, 1941, vol. 41, pp. 552-570). The authors report on an investigation of the stress-strain characteristics in tension and in compression of a number of carbon, silicon and low-alloy Special tests were made to illustrate the effect of different testing techniques and of the rolling direction. The conclusions reached were: (1) The average values of the upper and lower yield points of each type of steel tested were practically the same in compression as in tension; (2) the general shape of the individual stress-strain curves up to the upper yield point were very nearly alike in tension and compression, except that the limits of proportionality were usually higher in compression; (3) the greatest differences between tension and compression stress-strain characteristics were noted in specimens of silicon steel cut across the rolling direction; (4) the upper yield point averaged 8% higher in tension and 6.4% higher in compression than the lower yield point with approximately the same difference for each class of steel; (5) in tension, the average ratio of the upper yield point to the nominal maximum stress was 0.56 for the carbon steels, 0.55 for the silicon steels and 0.65 for the low-alloy steels; it made little difference whether the specimen was cut in or across the direction of rolling; (6) the direction of rolling affected the limit of proportionality, the true breaking stress and most of the ductility indices more than the other properties; (7) the differences in directional properties were most marked in the case of the silicon steel.

The Mechanical Testing of Wire and Some Related Phenomenon. G. Robinson. (Wire Industry, 1942, vol. 9, Feb., pp. 63–65, 77). In the concluding part of this paper (see p. 196 A) the author describes the Brinell, Vickers and Rockwell hardness tests as well as some twisting tests used only for wire. In one of the latter tests the wire is held horizontally and clamped at both ends in the separate grips of the machine; one set of grips is made to revolve at a specified speed, the other set does not revolve but is free to slide forward. The number of complete revolutions of one end of the wire before fracture on a length usually 100 times the wire diameter is reported together with information on the uniformity of the twisting. In another test the wire is held vertically and twisted at high speed while tension is simultaneously applied by a suspension weight.

A Rapid Method of Accurately Measuring Small Elongations of Tensile Test Bars. G. J. Thomas. (Journal of Scientific Instruments, 1942, vol. 19, Mar., p. 45). The author describes a technique by which the small elongations of fractured cast test-pieces can be accurately measured. After test the two pieces of the broken bar are pressed together in a vice; in this way the error due to the gap between the two pieces is eliminated, the fracture being usually almost invisible. The same calipers with the original dimensions are again used with the same mark at the shoulder end, and another line is inscribed on the bar. The distance between the lines marked before and after fracture is measured on a micro-

scope with a micrometer scale in the eyepiece.

The Plastic Deformation of Cast Iron. H. A. Nipper and E. Piwowarsky. (Giesserei, 1941, vol. 28, July 11, pp. 305–311). The authors review earlier work on the deformation of cast iron at different temperatures by rolling and pressing, and discuss the results of some of their own recent investigations. To obtain good deformation properties in the cold state it is necessary that the silicon and nickel contents should not exceed that necessary for graphitisation. Increasing the phosphorus content had the same effect as increasing the silicon, i.e., to decrease the compression strength and the deformability, although the effect on the latter was not so marked. A phosphorus content up to 0.35% is more likely to increase the tensile and bending strengths than to decrease them, which is a contradiction of the general belief that a moderate amount of phosphorus makes iron very brittle.

Fatigue of Metals. H. G. West. (Australian Institute of Metals: Australasian Engineer, 1941, vol. 41, Nov. 7, pp. 127–130). The author defines fatigue strength and discusses the relationship between fatigue strength and tensile strength, the diagnosis of fatigue failures, stress raisers and the detection of fatigue cracks by: (a) applying paraffin and whiting; (b) etching; (c) applying a luminescent compound and examining under "black light"; and

(d) magnetic methods.

Cast Iron: Fatigue Strength and Notch Sensitivity. I. The Effect of Frequency, Temperature and the Metal Matrix. R. Bertschinger and E. Piwowarsky. (Giesserei, 1941, vol. 28, Aug. 22, pp. 365–372; Sept. 5, pp. 385–389). The authors review the literature on how the frequency and temperature of testing and the previous heat treatment and structure of cast iron affect its fatigue strength and notch sensitivity. The influence of silicon, phosphorus, nickel, chromium, copper and vanadium are also dealt with. Some of the authors' own investigations in respect of these properties are also described.

A Pulsating Tension-Fatigue Machine for Small Diameter Wire. J. N. Kenyon. (Engineering Inspection, 1941, vol. 6, No. 4, pp. 8–14). The author describes a new type of pulsating-tension fatigue-testing machine in which the load is applied by employing 1942—i

three reciprocating forces, 120° out of phase, which exert a constant torque on the motor and thus eliminate unbalanced inertia effects. A gripping device is described and experience with it has shown that, in over 80% of the tests, the fracture occurs clear of the end connectors. The machine is specially suitable for testing used wire in order to determine the extent of the deterioration in its endurance properties.

Evidence on the State of Fatigue of Metals obtained from an Examination of the Surface Stresses by Means of X-Ray. R. Glocker and others. (Iron and Steel Institute, 1942, Translation Series, No. 79). An English translation of a paper which appeared in Zeitschrift des Vereins deutscher Ingenieure, 1941, vol. 85, Oct. 4,

pp. 793-800.

Comparison of Fatigue Strength of Steel Bolts and Studs Fitted with Steel or Mg Alloy Nuts. F. Kaufmann and W. Jäniche. (Iron and Steel Institute, 1942, Translation Series, No. 78). An English translation of a paper which appeared in Zeitschrift des Vereins

deutscher Ingenieure, 1941, vol. 85, May 31, pp. 504-505.

Standardization of Hardenability Tests. W. E. Jominy. (Metal Progress, 1941, vol. 40, Dec., pp. 911–914). A group of metallurgists representing seven of the leading American steelmakers and users has been working for some time on standardising test methods and in this paper two standard hardenability-test procedures which the group recommend are described. One method is to harden 3-in.-dia. specimens by the prescribed heat treatment, cut a transverse section midway between the ends and make a hardness traverse across the section. The second method is by the Jominy end-quench test on a 1-in.-dia. specimen. The results obtained in nine different laboratories on specimens from the same heats of steel are compared and show very close agreement.

Use of Hardenability Tests for Selection and Specification of Automotive Steels. A. L. Boegehold. (S.A.E. Journal, 1941, vol. 49, July, pp. 266–276). After pointing out the requirements of a hardenability test for industrial purposes, the author explains how the Jominy end-quench test answers the purpose. Details of the three types of specimen for this test which cover the desired ranges of bar size and cooling rates are given. The method of developing hardness/cooling-rate curves is shown and the application of the curves for the selection of a steel and the correct heat treatment to give it in order to produce a finished part with the desired hardness is explained in detail.

Determining Hardenability on Small Sizes. F. E. McCleary and R. Wuerfel. (S.A.E. Journal, 1941, vol. 49, July, pp. 276–278). The authors point out two limitations of the Jominy end-quench hardenability test, which are that the test-piece may not have a section large enough to develop the required cooling rates, and that for parts below $\frac{5}{8}$ in. in dia. a special test-piece has to be machined. They then describe a method using the Wuerfel

bomb. This bomb is a cone-shaped piece of steel $3\frac{3}{8}$ in, long tapering from 2 in, to $\frac{1}{2}$ in, in dia, with a $\frac{5}{16}$ -in, dia, hole down the centre provided with a screwed plug. The test-piece is a plain cylinder $3\frac{1}{2}$ in, long, slightly less than $\frac{5}{16}$ in, in dia. A small amount of a low-melting-point alloy, such as Wood's metal, is put in and the bomb is warmed to melt it; the test-piece is inserted and the plug screwed in. The alloy provides the thermal contact between the bomb and test-piece. The assembly is heated to the temperature suited to the steel under test and quenched in water. After warming the bomb to melt the alloy, the specimen is removed and hardness readings are taken along its length and a curve is plotted for hardness against the distance from the small end.

Determination of Specific Hardenability of Shallow-Hardening Steels. O. V. Greene and C. B. Post. (S.A.E. Journal, 1941, vol. 49, July, pp. 278–282). This paper was published previously in Heat Treating and Forging, 1941, vol. 27, Mar., pp. 120–121. (See Journ. I. and S.I., 1941, No. II., p. 52 A and this Journal, p. 111 A).

Correlation between Jominy Test and Quenched Round Bars. M. Asimow, W. F. Craig and M. A. Grossmann. (S.A.E. Journal, 1941, vol. 49, July, pp. 282-291). The authors suggest a method of correlating hardenability determinations obtained by the Jominy end-quench test with those obtained by fully quenching cylindrical bars of different sizes. They use this correlation to predict from Jominy test results what the hardness distribution would be in round bars when using a known severity of quench. The factor used for comparison is the "half-temperature time" which is the time taken in seconds to cool the specimen from the quenching temperature to the mean of the quenching temperature and that of the cooling agent. Experimental and practical methods of determining the half-temperature times for Jominy and for cylindrical bars are described, hardness/half-temperature-time curves are presented and an example is given of the method of predicting the hardness in a given size of round bar quenched with a known severity from Jominy test data.

The Work-Hardening and Ageing of Steel. J. H. Andrew and H. Lee. (Iron and Steel Institute, 1942, this Journal, Section I.). Experimental work was undertaken with a view to proving or disproving the hypothesis, formulated by one of the authors in 1938, that the cold-working of iron and steel gives rise to the formation of the γ phase. The authors are convinced that the experimental work described in this paper proves this contention. It is shown that earbon is dissolved during the work-hardening process, and that under certain conditions both austenite and martensite may form. A new theory of quench-ageing is suggested, and the subject of strain-ageing is also dealt with. The close correspondence between the changes produced in steel by coldwork and by quench-hardening is strong evidence in favour of the suggestions made. A new theory of the yield is developed, whilst

the changes undergone during the extension of the tensile testpiece are shown to be dependent upon the total elongation and the

condition of the carbide in the steel.

The Wear of Metallic Materials. A. Eichinger. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 13, pp. 247–265; Stahl und Eisen, 1941, vol. 61, Nov. 6, pp. 1023–1025). The author distinguishes between the following four processes by which the wear of metals takes place: (1) Sliding friction with lubrication causing uniform wear; (2) heavy wear and seizing which occurs with unlubricated surfaces or with water present; (3) flaking off, as occurs on the surface of rollers or wheel rims; and (4) frettage corrosion between round or flat surfaces in the dry state or with insufficient lubrication. Equipment and procedure for testing the resistance of metals to these four kinds of wear are described and methods of calculating the effects of liquids and the heat developed are explained.

Machinability. D. Taylor. (Automobile Engineer, 1942, vol. 32, Feb., pp. 51–56). The author considers the factors affecting the machinability of cast iron and steel and shows that the hardness and composition of the metal are not the only criteria of machinability. This property is also affected by the manner in which bar stock is finished; for example, a cold-finished product machines more freely than hot-rolled stock, and so does material that has

in some measure been cold-worked.

The Heat Treatment in a Magnetic Field of Permanent Magnet Alloys of High Coercive Force. J. S. Shur. (Russian Journal of Technical Physics, 1940, vol. 10, No. 9, pp. 757–760). (In Russian). The author examined the magnetic properties of a permanent magnet alloy having the composition nickel 25–28%, aluminium 11–13% and the remainder iron, after various forms of heat treatment, the object being to discover whether the coercive force could be increased by heat treatment instead of by adding the expensive element cobalt. The apparatus is described and illustrated. Soaking the sample for 1 hr. at 650° C. and quenching in water resulted in a marked increase in the coercive force and remanence. An English translation of this paper forms No. 73 of the Translation Series of The Iron and Steel Institute.

The Effect of Carbide Spheroidization upon the Creep Strength of Carbon-Molybdenum Steel. S. H. Weaver. (Proceedings of the American Society for Testing Materials, 1941, vol. 41, pp. 608–627). The author reports the results of creep tests on specimens of a 0·17% carbon, 0·42% molybdenum steel. These were prepared in twelve different conditions according to heat treatment and the degree of carbide spheroidisation. Two independent series of long-time creep tests were run on specimens in each condition, one series at 900° F., the other at 1000° F. The test data showed that whilst the initial creep stresses varied greatly for the different conditions of the steel, in some cases the creep stresses after 20 years

at 900° F. and 1000° F. would decrease by 54% and 77% respectively. The tests at 900° F. indicated that the normalised structure was of primary importance in producing good creep properties, whilst tests at 1000° F. showed that the coarse grain was of major importance and the effect of either normalising or annealing was

only of minor importance.

The Properties and Mode of Rupture of a Molybdenum and a Molybdenum-Vanadium Steel, Judged from Prolonged Creen Tests to Fracture. H. J. Tapsell, C. A. Bristow and C. H. M. Jenkins. (Proceedings of the Institution of Mechanical Engineers, 1941, vol. 146, No. 5, pp. 208-219). The authors describe an investigation of the creep properties of a 0.49%-molybdenum steel and a 0.54%molybdenum, 0.20%-vanadium steel, which was made primarily to provide data on the mode of failure and elongation at fracture. Observations made at intervals of about five days on the former steel showed that the commencement of spheroidisation and intercrystalline cracking became evident smimultaneously after 33 days of test when the extension was 1.35%, a stress of 7 tons per sq. in. being applied at 580° C. The results of prolonged tests demonstrate that there is considerable similarity in the creep behaviour of the two steels in the air-cooled condition, but that the creep resistance of the molybdenum-vanadium steel was somewhat better than that of the molybdenum steel. A comparison on a temperature basis for 0.2% creep in 10^5 hr. revealed that, at a stress of 3 tons per sq. in., the former steel was superior by only about 10° C. On a stress basis for temperatures from 490° to 550° C. the former steel behaved very favourably. The results of the microscopical examination of the fractures are discussed.

The Present Position of Rolled and Forged Heat-Resisting Steels. G. Riedrich. (Stahl und Eisen, 1941, vol. 61, Sept. 11, pp. 852-858). The author reviews the chemical composition, structure, scaling resistance and mechanical and physical properties of the heat-resisting steels now in use. The heat-resistance of austenitic chromium-nickel steels is increased by silicon additions, but if over 3% is added the resistance to hot-deformation is increased. The chromium-manganese-silicon steels may, however, contain more than 3% of silicon without the hot-working properties being affected. In the ferritic chromium steels 2.5-3% of silicon can replace about 10% of chromium and give equal heat resistance. Ferritic and ferritic-austenitic steels high in chromium are suitable for applications in gases containing sulphuretted hydrogen and in carburising atmospheres. The steels which resist the attack of sulphur dioxide are the ferritic chromium, chromium-silicon and chromium-silicon-aluminium steels, the ferritic-austenitic chromium steels low in nickel, and the austenitic chromium-manganese-silicon steels. Heat-resisting steels are not sufficiently resistant to the attack of molten aluminium and zinc, and molten chlorides, sulphides and cyanides, but are resistant to nitrates. Ferritic-austenitic

chromium steels low in nickel will also resist molten copper alloys. The austenitic heat-resisting chromium-nickel steels with up to 30% of nickel tend to become brittle after prolonged loading at temperatures in the 600–900° C. range because of the precipitation of carbide and/or the compound FeCr. Austenitic steels containing some ferrite become cold-brittle after prolonged loading in the above temperature range. The tendency to brittleness due to the precipitation of FeCr of ferritic-austenitic steels with about 25% of chromium and low in nickel can be counteracted by keeping the nickel below 3%. Ferritic steels become cold-brittle after prolonged loading at temperatures exceeding 950° C., whilst the ferritic-austenitic steels do not. Ferritic steels with more than about 15% of chromium also become cold-brittle after prolonged stressing in the 400–500° C. range and this is more marked with increasing chromium contents.

Investigations on the Suitability of Heat Resistance Materials for Combustion Engines. Part IV. H. Cornelius and W. Bungardt. (Iron and Steel Institute, 1942, Translation Series, No. 80). An English translation of a paper which appeared in Luftfahrtforschung,

1941, vol. 18, No. 9, Sept. 20, pp. 305-310).

The Application Possibilities of Stainless and Heat-Resisting Steels Containing Nitrogen Additions. F. Rapatz. (Stahl und Eisen, 1941, vol. 61, Nov. 27, pp. 1073-1078). The author reviews the chemical composition, production, working up, properties and possible applications of steels containing chromium, chromium and nickel, manganese, and chromium and manganese, to each of which more than 0.05% of nitrogen was purposely added in the bath. Steels nitrided by diffusion in the surface are not included in this paper. The nitrogen extended the stability range of the austenite and improved the properties of the austenitic steels. The nickel content of chromium-nickel stainless steels could be reduced if nitrogen were added. Chromium-manganese-nitrogen steels were more ductile than chromium or chromium-manganese steels and had practically the same corrosion resistance. The high creep strength of the steels containing nitrogen, especially the chromium-manganese-nitrogen steels, renders them suitable for use at high temperatures, but they are only non-scaling at up to 850° C.

New Data for Evaluating Manganese-Molybdenum Steels. R. M. Parke, J. R. Blanchard and A. J. Herzig. (Metal Progress, 1941, vol. 40, Dec., pp. 906–910). Owing to the increased use of manganese-molybdenum steels in place of chromium-nickel steels, more information on the hardenability of the former is required. The authors present hardness curves plotted from data obtained by Jominy end-quench tests on a number of steels containing up to 0.41% of molybdenum and up to 1.70% of manganese, as well as S-curves for two of the steels containing 0.17% and 0.36% of molybdenum respectively.

Influence of the Molybdenum Content upon the Properties of High-Speed Tungsten-Free Tool Steel. D. W. Rudorff. (Metallurgia, 1941, vol. 24, July, pp. 88-91). The author gives an account of a recent investigation by Gulvaev of the effect of adding different amounts of molybdenum to high-speed steels containing carbon 1.3%, vanadium 4.2% and chromium 4.3%. An addition of 1% of molybdenum considerably increases the stability of the austenite, but greater additions add very little to the stability achieved by 1%. The higher the molybdenum content the more refined is the structure of the austenite at a given hardening temperature. The results of tool life tests indicated that: (1) Adding 2-2.5% of molybdenum to a 4%-vanadium, 4%-chromium steel improves the cutting properties, but further additions do not prolong the total life; (2) the initial carbon content of 1.3% can be lowered to about 1.05% without diminishing the cutting properties; and (3) adding 3% of tungsten causes only an insignificant improvement in the cutting properties.

The Strength Properties of Chromium-Manganese-Molybdenum Heat-Treatable Steels. H. Cornelius and H. Krainer. (Stahl und Eisen, 1941, vol. 61, Sept. 18, pp. 871–877). The authors report on an investigation of the structure, hardness, elastic limit, tensile strength, necking, notch-bar impact strength, brittleness after tempering and torsional fatigue strength of two types of chromium-manganese-molybdenum steel. These types contained 1% and 1·4–1·8% of manganese, and 3% and 2% of chromium respectively. The tests were made on specimens from 40 to 140 mm. in dia. having tensile strengths in the 90–140 kg. per sq. mm. range. The results showed that for making highly stressed engine parts there was no advantage in increasing the manganese beyond 1%, chiefly because the higher manganese steels had too much temper brittleness and

too many slag inclusions.

The Influence of the Vanadium Content upon the Properties of Low-Alloyed High-Speed Tool Steels. D. W. Rudorff. (Metallurgia, 1942, vol. 25, Jan., pp. 79-81). The author reports the results of an investigation by Gulyaev on the effects of additions of up to 6.7% of vanadium to high-speed tool steel containing about 4% of chromium; 3% of tungsten and 3% of molybdenum. The effects of vanadium on the hardness obtained after tempering at various temperatures in the 100-650° C. range were: (1) For a given temperature, or for a given holding time, the temperature of the secondary martensitic transformation increased with increasing vanadium content: and (2) the amount of residual austenite for a given temperature range decreased with increasing vanadium Red-hardness tests were also made at temperatures in the 500-700° C. range, and the conclusions reached were as follows: (1) Specimens hardened from the highest temperature showed the best hardness stability; (2) with the exception of the steel containing carbon 1.5% and vanadium 6.7%, the hardness remained stable

for 5–10 hr. at 550° C.; (3) all the steels tested lost their hardness rapidly at 700° C.; and (4) the best red-hardness results were obtained at 600–650° C. The cutting properties were also investigated and the optimum vanadium content in respect of tool life was

found to be 2.5%.

Recent Developments in Alloy Steel Castings. H. L. Korschan. (Giesserei, 1941, vol. 28, July 25, pp. 325–332; Aug. 8, pp. 350–355). The author reviews developments since 1930 in the manufacture and properties of low-alloy and high-alloy steel castings, dealing in turn with steels alloyed with silicon, manganese, nickel, chromium, chromium-nickel and chromium-tungsten.

Substitution Alloy Steels (low Ni-Mo-W Steels) in Aero Engine Construction. H. Wiegand and R. Scheinost. (Iron and Steel Institute, 1942, Translation Series, No. 81). An English translation of a paper which appeared in Luftwissen, 1941, vol. 8, Oct., pp.

305-309.

The Effect of Segregation and Forging on the Strength Properties of Large Steel Forgings. W. Coupette. (Stahl und Eisen, 1941, vol. 61, Nov. 6, pp. 1013-1022; Nov. 13, pp. 1036-1042). The author reports on an investigation of the effects of the primary structure, segregation and forging on the tensile strength and impact strength of specimens cut from forgings of 12 to 110 tons of a killed carbon steel containing carbon 0.4% and manganese 0.9% and of a chromium-nickel-molybdenum-vanadium steel. The effects of the primary columnar structure and of segregation were determined separately on specimens which were submitted to various degrees of forging. The previous primary structure had no noticeable effect on the strength of unforged steel which had been heat-treated to produce a uniform secondary structure. The reduction of area and elongation values of transversely cut specimens were markedly reduced by segregation whilst the impact strength was only slightly reduced. Repeated forging did not diminish. but rather increased this detrimental effect. Forging once or twice, however, markedly improved the properties of slightly and moderately segregated areas. Whatever the degree of segregation, the maximum toughness was produced by two or three forging treatments. The elastic limit was not affected by segregation. Any segregation effect on longitudinal specimens was completely nullified by forging twice or three times. Further tests were made on a 110-ton ingot of a 0.45% carbon steel and a 52-ton ingot of a chromium-nickelmolybdenum-vanadium steel which were forged in a 4000-ton press. With transversely cut specimens it was noted that the greater the degree of segregation, the more were the reduction of area and elongation values reduced with a comparatively slight falling off in the impact strength. With the alloy steel ingot the effects of forging did not penetrate fully to the centre, although the properties of transversely cut specimens were quite satisfactory after two forging treatments.

The Manufacture of Crankshafts in High-Duty Cast Iron. E. M. Currie and R. B. Templeton. (Institute of Marine Engineers: Foundry Trade Journal, 1942, vol. 66, Feb. 26, pp. 133–135; Mar. 5, pp. 149–151). The authors discuss the possibility of substituting cast crankshafts of high-duty iron for forged steel crankshafts, present the results of trials by engine builders, and describe methods of making tensile, fatigue, notch-sensitivity and dampingcapacity tests. The importance of design is particularly stressed. The designer should take full advantage of the fact that almost any shape can be produced with ease and should not copy forged crankshaft design. The cored shaft with shaped webs assists materially the metal flow in the mould; it avoids the abrupt changes of section and sharp corners; the solidification of the metal is synchronous and the resultant structure is more uniform. The lower modulus of elasticity of cast iron can be overcome by increasing the diameter, but a saving in weight compared with forged shafts is possible by making them hollow. Machining allowances can be cut down and complicated designs can be accurately produced.

Testing for Strength or Porosity. S. F. Dunkley. (Engineering Inspection, 1941, vol. 6, No. 4, pp. 21-27). The author describes and illustrates equipment for testing castings, tubes and tube fittings for porosity, leaks and cracks by immersing them in water and supplying air under pressure to the interior. Examples are given of the types of fault usually found.

Determining the Composition of Steel by Spark Tests. (Machinery, 1942, vol. 60, Feb. 26, pp. 128–129). Some details are given of the application of the spark test as a simple and rapid check on the carbon contents of steel. By applying a portable grinder to the ends of a pile of bars, the presence of a bar of composition outside the limits specified for that particular stock can be rapidly detected

by a skilled operator.

Sampling Inspection and Quality Control. B. P. Dudding. (Journal of the Institution of Production Engineers, 1942, vol. 21, Jan., pp. 13-34). The author explains the application of statistical methods for the detection of causes of variations in the quality or dimensions of mass-produced articles and gives examples. It is shown how statistical methods can serve as a warning that a change

in the production system may be occurring.

Railway Rolling Stock Material. (British Standards Institution, No. 24, 1942). This Standard Specification constitutes the sixth revision of the standard for railway material first published in Part 1 covers locomotive, carriage and wagon axles; Part 2 covers locomotive, carriage and wagon tyres and methods of fastening locomotive tyres; Part 3 covers springs and spring steel; Part 4 covers steel forgings, blooms and castings; Part 5 is devoted to non-ferrous material; Part 6 covers steel plates, sections, bars and rivets for locomotive boilers, locomotives, carriages and wagons.

Data on Cast Iron. (British Standards Institution, No. 991—1941). This Report is intended for engineers and designers, and aims at placing before them concise data on the various grades of cast iron available in industry in this country at the present time.

War Emergency British Standard Schedule of Drums and Sheet Steel Containers for British Packers in the United Kingdom for the Home Trade. (British Standards Institution, No. 993—1941).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 203 A-207 A)

Research in the Iron and Steel Industry. F. T. Sisco. (Report of the National Research Council: Foundry Trade Journal, 1942, vol. 66, Jan. 29, pp. 67–69; Feb. 5, pp. 87–88, 86). This paper comprises a report of the National Research Council to the National Resources Planning Board (of the United States). In it the contributions to fundamental metallurgical research and to process research by the leading industrial nations of the world from 1850 to the present time are reviewed.

The Electron Microscope, the Supermicroscope and Metallurgical Research. W. Henneberg. (Iron and Steel Institute, 1942, Translation Series, No. 77). An English translation of a paper which appeared in Stahl und Eisen, 1941, vol. 61, Aug. 14, pp.

769-776. (See p. 70 A).

The Application of Radiography in the Inspection and Control of Welds. J. J. Gillespie. (Engineering Inspection, 1941, vol. 6, No. 4, pp. 15–20). The author describes the welding technique and the X-ray testing of welds at a works making welded high-pressure vessels, giving details of faults and their classification, their effect on mechanical efficiency, preparation of the weld for examination, use of intensifying screens, a telescopic focusing device, development of films and interpretation of the radiograms.

Grain Size Control in Steel. H. O'Neill. (Engineer, 1942, vol. 173, Feb. 20, pp. 158–159). The author reviews the advantages of being able to control the grain size of steel and explains the effects of fine and coarse grains on the properties by reference to simple analogies. He regrets that there is in Great Britain no agreed standard of reference for grain size as in Sweden and America. The relation of grain size to shallow-hardening and deep-hardening properties is briefly explained and the attention of structural engineers is drawn to the fact that the weldability of high-tensile steel depends largely on its hardenability which is in turn affected by the grain size.

ANALYSIS

(Continued from pp. 163 A-167 A)

First Report of the Standard Methods of Analysis Sub-Committee. (Iron and Steel Institute, 1942, this Journal, Section I.). In this First Report the Standard Methods of Analysis Sub-Committee of the Committee on the Heterogeneity of Steel Ingots (a Joint Committee of The Iron and Steel Institute and The British Iron and Steel Federation) recommend methods that they have devised, from both theoretical considerations and practical experiments, for the determination of sulphur and of phosphorus in carbon steels.

The recommended method for sulphur is a refinement of the gravimetric aqua-regia/barium-sulphate process, and for the determination of phosphorus the Sub-Committee recommends a modified bromide process, whereby arsenic is eliminated prior to the precipitation of the phosphorus as the yellow precipitate, in view of the

fact that practically all commercial steels contain arsenic.

Precise details are laid down regarding analytical procedure, and notes are appended drawing attention to the precautions needed to ensure reproducible results within the specified degree of accuracy expected when all practical instructions are rigidly adhered to.

In the case of both elements, the Sub-Committee is unanimously of the opinion that the recommended methods cannot be expected to yield consistent results closer than $\pm 0.0015\%$ of the true sulphur

and phosphorus contents of the steel.

It is emphasised that the methods recommended were devised primarily for "referee" purposes, and, therefore, little cognisance was taken of the time or expense involved in the determination of either element. The main object was to devise standardised processes yielding comparable results when carried out by different chemists using the same samples of steel.

The Report concludes with a recommended method for the determination of lead in steel. This method, based on the initial separation of the lead as lead sulphate and its subsequent conversion to lead molybdate, was subjected to rigid examination and experi-

ment, and remarkably close agreement was obtained.

Note on Spectrographic Analysis as a Means of Testing for Sea-Water Damage on Metals. S. H. Wilson. (Journal of the Society of Chemical Industry, 1941, vol. 60, Nov., pp. 286–288). Procedure is described for preparing a solution of the corrosion product of a metal for spectrographic analysis by the spark method. Comparison of the spectrogram of this solution with that of the residue from sea-water, using the lines sodium 3302·3, potassium 4044·2, calcium 4226·7 and magnesium 2852·1, will indicate whether the corrosion is due to sea-water or other cause. Confirmation of sea-water damage may be obtained from the presence of a definite strontium

line. The use of an interrupted arc is shown to give a more definite

test for potassium.

A Method for the Investigation of Minute Surface Particles by Spectrum Analysis. G. Thanheiser and J. Heyes. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 3, pp. 31–39; Archiv für das Eisenhüttenwesen, 1941, vol. 14, May, pp. 543–550). The authors discuss the difficulties arising in making spectrum analyses of minute inclusions in the surface of metals and describe the technique they developed which enabled such analyses to be made of inclusions with a surface area of a few thousandths of 1 sq. mm. Two methods of making drills with a diameter of about 0.01 mm. and the drilling of mica strips are described. The mica is fastened across the specimen so that the minute hole is over the inclusion the composition of which is to be determined. A small spark is struck through the hole and this excites the inclusion. Examples are given of the results obtained using this technique for inclusions in steel.

Colorimetric Analysis. (Wild-Barfield Heat-Treatment Journal, 1941, vol. 4, Sept.—Dec., pp. 67–70). A description is given of the Spekker Photoelectric Absorptiometer with which qualitative analyses of the metallic elements in steel can be made. The instrument consists essentially of a light source, a glass cell for the solution, a photoelectric cell which receives the light transmitted by the solution, another opposed cell for compensation and a measuring device to determine the difference in currents set up in the cells. The instrument is first calibrated by using a set of solutions of known concentration and a graph is plotted from the instrument readings and these concentrations. The concentration of an unknown solution is then determined by referring the instrument drum reading for the unknown solution to the calibration curve.

Methods for the Photometric Determination of Copper in Iron, Steel and Alloy Steels. G. Bogatzki. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, May, pp. 551–553). The author describes a method of determining low copper contents in iron and steel without using sulphuretted hydrogen. The copper is extracted with ammonia from the solution containing the dissolved sample. The copper is converted with sodium sulphide to a colloidal copper sulphide, the yellow-brown colour of which is measured photometrically. In high-alloy steels the interference of nickel is overcome by using more concentrated ammonia, and, if cobalt is present, this is precipitated as calcium cobalt nitrite. The detailed procedures for iron and carbon steels and for alloy steels are given.

The Photometric Determination of Copper in Steel. K. Quandel. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, June, pp. 601–604). The author critically examines the known colorimetric methods of making copper determinations and their suitability for copper-bearing steel. He then describes in detail a satisfactory photometric method by which the copper in steel can be determined in 15–20 min.

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The Photometric Determination of Molybdenum in Steels and Cast Iron Using Hydrogen Peroxide. G. Thanheiser and P. Göbbels. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 11, pp. 187–194). The authors describe a photometric method of analysis which they developed for determining molybdenum in steel and cast iron; it is based on the yellow colour formed by adding hydrogen peroxide to the solution containing molybdenum. Concentrated phosphoric acid proved to be a suitable solvent, as with it there was no colour interference from either vanadium or titanium and there was practically no natural colour due to the iron in solution. Check analyses by other methods established the accuracy of the results. The new method takes about 20 min. excluding the time required to dissolve the sample. Slight modifications of the procedure for analysing cast iron and steel containing columbium and tantalum are given.

Rapid Photometric Determination of Silicon in Steels. R. Weihrich and W. Schwarz. (Archiv für das Eisenhüttenwesen, 1941, vol. 14, Apr., pp. 501–503). The authors describe a rapid photometric method which can be used for determining up to 4% of silicon in carbon steels and in some alloy steels. The method has proved very useful for steelworks process control except in the case of high-alloy chromium-tungsten and chromium-molybdenum

steels.

The Determination of Silicon, especially in Steel and Iron. K. L. Weiss. (Archiv für das Eisenhüttenwesen, 1941, vol. 15, July, pp. 13–17). In the determination of silica or silicon in ores, iron, steel and slags, the silica in the first hydrochloric acid solution is in the hydrated form; it must be baked to render it filterable, and this requires much time. The author describes the use of gelatine, glue or isinglass to enable the silica to be filtered off more rapidly.

The Photo-Colorimetric Examination of Alloy Pig Iron and Cast Iron. II. Determining Chromium. H. Pinsl. (Giesserei, 1941, vol. 28, Oct. 17, pp. 429–434). The author describes two photometric methods of determining chromium in iron. The first is by solution of the sample in acid, oxidation of the chromium with potassium permanganate, separation of the iron from the chromium with caustic soda and measuring the intensity of the chromate colour in an alkaline solution. In the second method the chromium is dissolved in sulphuric acid, oxidised with ammonium persulphate and the intensity of the chromate colour is measured. The former method is applicable generally to both high- and low-alloy irons and steels, whereas the latter is confined to low-alloy materials soluble in sulphuric acid and not containing any element which interferes with the chromate colour.

Steel Analyses by Drop Reactions. G. Thanheiser and Maria Waterkamp. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1941, vol. 23, No. 6, pp. 81–96; Archiv für das Eisenhüttenwesen, 1941, vol. 15, Sept., pp. 129–144). The authors

describe procedures for detecting the presence of aluminium, chromium, copper, manganese, molybdenum, nickel, phosphorus, sulphur, silicon, titanium, vanadium and tungsten in steel by means of drop reactions which are not harmful to the surface of the specimen. The details given include the method of preparing the specimen, applying a drop of the testing solution and separating the element in question from the iron, together with the results obtained in numerous tests.

Zinc Reduction Method for the Determination of Iron. H. Skolnik and W. M. McNabb. (Metal Finishing, 1941, vol. 39, June, pp. 241–242). The authors describe a modification of the Jones method for the reduction of ferric iron with zinc with the subsequent titration of the ferrous iron with a standard oxidising

agent.

The Lundegårdh Apparatus: Its Construction and Use. J. A. C. McClelland and H. K. Whalley. (Journal of the Society of Chemical Industry, 1941, vol. 60, Nov., pp. 288–291). An account of the Lundegårdh apparatus for the examination of flame-emission spectra is given. Details of the construction are included which would enable other laboratories to build a similar apparatus, for which there appears to be a demand; information is also given on the interpretation of the spectrograms obtained and the application of the flame technique which will give some indication of the type of problems that such an apparatus would solve in a spectrographic laboratory.

BOOK NOTICES

(Continued from pp. 128 A-130 A)

Association of Iron and Steel Engineers. "The Modern Strip Mill." A Recording of the continuous wide strip mill installations and practices in the United States. 4to, pp. 364 + 127. Illustrated. Pittsburgh, 1941: The Association. (Price £6.)

The Iron and Steel Engineer, which is the official journal of the Association of Iron and Steel Engineers, has, from its inception, set itself a high standard both in the nature of its matter and get-up. In the course of recent years it has published descriptions of nearly all the wide strip mill installations which have been laid down in American steelworks that were notable for the amount of detail given. Last year it was decided to review the information thus available and re-publish it with amplification in book form for readier reference and permanent preservation. This recently appeared under the title of "The Modern Strip Mill" as a handsome volume of 12 in. \times 9 in. whose general effect is only marred by the intrusion of advertising matter throughout the text. The book is divided into two parts, the first, in which the general features of wide strip production facilities are systematically dealt with, and the second giving descriptions of

each of the American installations in more or less tabular form, these being arranged in the order of their going into commission. At the end of the volume are well-reproduced layout drawings of each plant

in the form of folding plates printed to resemble blue-prints.

The matter assembled in the first part is somewhat uneven in quality. In the first chapter, for example, not only is the historical aspect of wide strip production alluded to, but consideration is also given to steel melting and pouring practices to meet the special requirements of these products. The preparation of slabs is also dealt with. In view of the importance of the steelmaking and ingot phases as well as of the supply of suitable well-conditioned slabs as the foundations of efficient wide strip production, more attention could usefully have been given to the metallurgical and engineering aspects of these vital preparatory steps in the sequence of manufacture. This chapter might have been expanded or sub-divided with advantage. Again, the importance of the flying shears employed for trimming the leading end of strips emerging from the finishing stand of the hot mill and cutting-up flat stock would have justified more consideration of their design.

Other chapters such as those dealing with the heating of slabs, the hot strip mill, mill parts and accessories, cold reduction facilities, &c., whilst notable for the descriptive detail and general data given, are often lacking in a critical attitude, so that what is best tends only to emerge by inference rather than by analysis. Nevertheless, the information given is of considerable value to all interested in the flat rolling of steel and its subsequent further processing as required for different flat rolled products, and the book will be warmly welcomed

by all such readers.

There is hardly a single piece of equipment entering into a modern wide strip mill plant which has not been touched upon. One of the few omissions is that no allusion is made to the hydro-electric type of slab squeezer which has been employed in several recent wide hot strip mills for correcting the slab width after the "broadsiding" operation in place of the less rational and more complicated and costly electro-mechanical type.

G. A. V. Russell.

Association of Polish Engineers in Great Britain. "Anglo-Polish Translation of Workshop Terms." Compiled by W. Bastyn and E. Pasykowski. 8vo, pp. 43. Illustrated. London, 1941: The Association. (Price 3s.)

The Polish engineers in this country are determined to play their part in the successful termination of the war, and to enable them to increase their effort and to overcome to a certain extent the difficulties of the English language this brochure has been produced. A wide variety of machine tools in present-day use are well illustrated, and the Polish and English terms are given in each case. The publication is intended essentially for the machine-tool operator rather than for the student, and it will also prove useful in the training of English operatives who must be familiar with the names of those machine-tool parts in wide use for the production of munitions.

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SUBJECT INDEX.

[References to the papers read before the Institute are indicated by the word Paper following the page number. The letter P, denotes a reference in Section I, of the Journal which contains the reports of the proceedings of meetings, the papers read, and the discussions thereon. The letter A. denotes a

reference to the section dealing with abstracts.

Indexing of Alloy Steels and Other Alloys. In the indexing of alloy steels, carbon and iron are ignored and the alloying elements contained in the steel are arranged in alphabetical order; for example, all references to nickelchromium-molybdenum steel will be found under the heading chromiummolybdenum-nickel steel. In the indexing of other alloys, carbon and iron, when present, are included in the title; iron, when present, is always mentioned first and the other elements follow in alphabetical order, carbon being in all cases mentioned last. Examples: "Iron-silicon-carbon alloys" and "ironchromium-nickel-carbon alloys."]

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